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MANUAL

OF

PHYSIOLOGY.

BY

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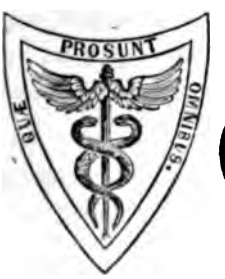
ST. BARTHOLOMEW'S HOSPITAL.

Second American, from the Second London Edition.

WITH

ONE HUNDRED AND SIXTY-FIVE ILLUSTRATIONS.



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AMERICAN PUBLISHERS' NOTICE.

This edition has been reprinted from the Second London Edition with but little alteration. The industry of the authors having embodied in it such notices of the more recent investigations and discoveries as were compatible with the design of the work, but few additions have been found requisite. The principal change will be observed in the introduction of a large number of new and superior illustrations, which, it is hoped, will render the facts advanced more easy of comprehension by the student. As in the former American Edition, the steel plates of the original have been engraved on wood, and scattered through the text, in their appropriate places, as more convenient for reference; and the title of "Manual" has been retained, in place of "Handbook," as being better suited to the character of the work. The editorial supervision to which it has been subjected in its passage through the press is a guarantee that the present edition will in no way detract from the reputation which the work has so deservedly attained.

Philadelphia, *January*, 1853.

PREFACE TO THE SECOND EDITION.

THE rapid sale of the First Edition of this Handbook, together with the general expressions of approval which have been kindly bestowed on the work, seemed sufficient to justify me in adhering to the plan and arrangement originally adopted. In preparing the Second Edition, therefore, little else has been done than carefully revising each portion of the work, and making such additions and alterations as our advancing knowledge in the science appeared to demand.

WILLIAM SENHOUSE KIRKES.

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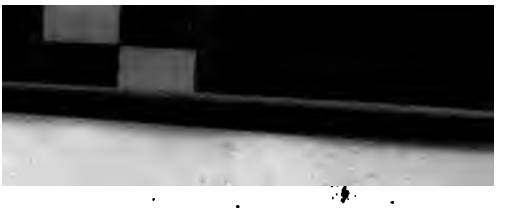

PREFACE TO THE FIRST EDITION.

THE publishers of Dr. Baly's edition of "Müller's Elements of Physiology" had long designed to render that admirable work more available for the general use of students. They had proposed the reduction of its principal contents into a volume more nearly proportionate to the share of time which can be devoted to Physiology, as only one of many subjects to be studied, in the period of pupillage. The present work was commenced with the intention of fulfilling their design; it was announced as a "Handbook of Physiology on the Basis of Müller's Elements;" and many of its chapters, namely, those on MOTION, VOICE and SPEECH, THE SENSES, GENERATION, and DEVELOPMENT, are chiefly abstracts of corresponding portions of that work, and of the Supplement by Dr. Baly and myself. But, in the rest of the subjects, it was found that the progress of Physiology during seven years had so increased or modified the facts, and some even of the principles of the science, that "Müller's Elements," and the notes added by Dr. Baly, could only be employed as among the best authorities and examples. The design was, therefore, departed from, so far as it concerned the construction of a Handbook on the basis of Müller.

In writing the present work, the primary object has been to give such an account of the facts and generally admitted principles of Physiology as may be conveniently consulted by any engaged in the study of the Science; and, more especially, such an one as the student may most advantageously use during his attendance upon Lectures, and in preparing for examinations. The brevity essential to this plan required that only so much of Anatomy, Chemistry, and the *other sciences* allied to Physiology, should be *introduced as might serve to remind* the reader of knowledge already

acquired, or to be obtained, by the study of works devoted to these subjects. For the same end, it was necessary to omit all discussions of unsettled questions and expressions of personal opinion; but ample references are given, not only to works in which these may be read, but to those by which the study of Physiology may be, in its widest extent, pursued.

For the convenience of students, the subjects are arranged on a plan corresponding with that in which they are taught in the courses of Lectures on Physiology, delivered in the principal metropolitan schools of medicine.

I cannot sufficiently express my obligations to Mr. Paget, from whom I have received the most liberal aid in every stage of the work, and who has, moreover, afforded me access to his manuscript notes of Lectures. I have also to offer my best thanks to Dr. Baly, for many kind suggestions made by him in the course of the work.

WILLIAM SENHOUSE KIRKES.

College of Saint Bartholomew's Hospital,
Sept. 29, 1848.

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INTRODUCTION.

HUMAN PHYSIOLOGY is the science which treats of the conditions, phenomena, and laws of the life of the human body in the state of health.

The phenomena of life manifested in the human body, as in that of all animals, may be arranged in two principal classes; the first comprehending those which are observed, in various degrees of perfection and variously modified, in both vegetables and animals; the second, those which are peculiar to the members of the animal kingdom.

The first class of the phenomena of life includes: 1st. The processes of digestion, absorption, secretion, excretion, circulation, and respiration, which, together with the offices of some parts not yet understood, fulfil their purpose in the formation, movement, and purification of the blood, with the materials for the nutrition of all the tissues of the body; 2d. The processes of growth and nutrition, or nutritive assimilation, by which the several parts of the body, obtaining materials from the blood, repair the loss and waste to which they are subject in the discharge of their functions, or through their natural impairment and decay; 3d. The generative processes, for the formation, impregnation, and development of the ova.

These are named processes, functions, or phenomena of organic or vegetative life. Those of the first two divisions maintain the existence of the individual being; those of the third maintain that of the species.

The second class of vital phenomena includes the functions of sensation and voluntary motion, by which the mind of an animal acquires knowledge of things external to itself, and is enabled to act upon them. These are named phenomena of animal or relative life.

But the division of the functions or phenomena of life into these, or any similar classes, is artificial, and must not be taken as indicating absolute *difference and dissociation*. The organic and *the animal life are knit together* and mutually dependent; neither *can be long maintained without* the other. As all the processes of

organic life are essential to the maintenance of the organs of animal life, so, in an equal degree, the sensation and voluntary motion of animal life are essential to the taking of food, the discharge of excretions, and other processes of organic life, by which the animal and the species are maintained.

All the bodies in which the phenomena of life have been observed are formed of diverse mutually adapted parts, or organs; they are, therefore, called organisms, or organized bodies or parts; their composition and structure, being peculiar, are named organic, and constitute their organization. While alive, also, they manifest certain peculiar *vital* properties and modes of action. A brief account, therefore, of the chemical composition, general anatomical structure, and vital properties of the several tissues and organs, will be a necessary preface to the consideration of their actions.

CHAPTER I.

CHEMICAL COMPOSITION OF THE HUMAN BODY.

THE following *Elementary Substances* may be obtained, by chemical analysis, from the human body: Oxygen, Hydrogen, Nitrogen, Carbon, Sulphur, Phosphorus, Silicon, Chlorine, Fluorine, Potassium, Sodium, Calcium, Magnesium, Iron, and probably, or sometimes, Manganesium, Aluminium, and Copper.

Thus, of the fifty-five elements of which all known matter is composed, nearly one-third exist in the human body. A few others have been detected in the bodies of other animals; but no element has yet been found in any living body which does not also exist in inorganic matter.

Of the elements enumerated above, the first four, because they exist in nearly all animal substances and form the largest parts of all, are named *essential elements;* the rest, being less constant, and occurring often in only very small quantity, are named *incidental elements.* But the term *incidental* must not be understood to imply that any of these elements (except, perhaps, the last three) are less necessary to the right composition of the substances in which they exist than the essential elements are. Sulphur, for example, is as constant and necessary a constituent of albumen, and iron of hæmatosine, as any of the elements are. The terms must be taken in only a general sense. No organic substance being known which has not at least three of the first four elements, they may be considered essential to the formation and existence of organic matter.

But one or more of the other elements added to these, in comparatively small proportions, contribute to determine, as it were incidentally, the peculiarities by which one kind of organic matter is distinguished from another.

The elements composing organic and inorganic matter being thus the same, we must look to the modes in which they are combined for an explanation of the differences between the two classes of substances. We cannot, indeed, draw an absolute rule of chemical distinction between the two classes, for there are substances which present every gradation of composition between those that are quite organic and those that are inorganic. Such substances of intermediate composition are many that are formed when inorganic matters, taken as nutriment by plants, gradually assume the characters of organic matter, under the influence of the vital properties of the plant; and such are those which are formed in both plants and animals, when, out of the well-organized tissues, or out of the sap or blood, materials are being separated, to form either tissues for mechanical service, or stores for nutriment, or purifying excretions. In both cases, the substances that are in the state of transition between the organic and the inorganic, or between the more and the less organized states, may proceed through changes so gradual that no natural line of demarcation between the two states can be discerned; and one cannot say when that which has been called inorganic has acquired the characters of an organic body, or when that which has been organic ceases to deserve the name. Alcohol, ether, acetic acid, urea, uric acid, and the fatty and oily matters, are such substances of organic origin, and intimately related to such as no one would hesitate to call organic, yet in their simplicity and mode of composition they are like inorganic matters.

But although no decided difference in chemical characters can be discerned in substances that thus stand, as it were, on the boundary between the organic and the inorganic world, yet, all the substances that form the proper component living tissues of animal bodies are as distinguished from inorganic substances as the actions of living bodies are from the passiveness of dead; and, as a general rule, it may be held that the more active the vital processes are that are carried on in any substance, the more widely do the chemical characters of that substance differ from those of inorganic matter.

The chief *peculiarities in the chemical characters* of animal substances appear to be these three:—

1. The simplest of the compounds naturally formed in the body —of those compounds which, from their being supposed to stand, in order of simplicity, nearest to the elements, are called *proximate principles*—are composed of at least three elements. In the inorganic world, the most abundant substances are either in the elemental state, as the oxygen and nitrogen, by the mixture of

which the atmosphere is formed; or, are formed by the union of only two elements, as water, of oxygen and hydrogen, the oxides of calcium, aluminium, and others. In the organic world, the most abundant substances are, in plants, compounds of three elements, as starch, gum, sugar, cellulose, and others composed of carbon, hydrogen, and oxygen; and in animals, of four or five elements, as albumen, fibrine, gelatine, and other compounds of the four essential elements and sulphur.

2. In the more compound inorganic substances, the several elements of which they consist appear to be combined, or, as it were, put together, in pairs—each element seeming to have more affinity for one of the others than for all the rest. The elements are arranged in what is called a *binary* mode of combination. But, when any number of elements are combined in an organic compound, they appear all held together as with one bond, as if each of them were united with equal force to all the others. Thus, for example, carbonate of ammonia, which is regarded as an inorganic salt, is formed of the same four elements as compose most animal matters. Its constitution may be thus expressed:—

Carbon, Oxygen, uniting, form carbonic acid,
Nitrogen, Hydrogen, uniting, form ammonia,
and these two uniting, form carbonate of ammonia.

And in the analysis of this substance, the first pair of elements may be separated together in the form of carbonic acid, the second pair remaining as ammonia. But, in stating the composition of an organic body, these four elements would be all placed within one bond, or bracket; and in the analysis of such a compound the elements part asunder, and recombine in compounds, which vary according to the circumstances in which the change takes place, and of which compounds there may be no reason to believe that any previously existed in the substance analyzed. Thus, in the decomposition of albumen, carbonic acid, water, ammonia, carburetted and sulphuretted hydrogen, and other compounds, would be, not merely separated, but formed out of the elements parting asunder, and combining again according to their several affinities and the circumstances of the case.

3. Not only is a large number of elements combined in an organic compound, but a large number of equivalents or atoms of each of the elements are united to form an equivalent or atom of the compound. In the case of carbonate of ammonia, already referred to, one equivalent of carbonic acid is united with one of ammonia; the equivalent or atom of carbonic acid consists of one of carbon with two of oxygen; and that of ammonia of one of nitrogen with three of hydrogen. But in an equivalent or atom of fibrine, or of albumen, there are of the same elements, respectively,

48, 15, 12, and 39 equivalents, according to Dumas, and nearly ten times as many according to Mulder. And, together with this union of large numbers of equivalents in the organic compound, it is further observable, that the several numbers stand in no simple arithmetical relation one with another, as the numbers of equivalents combining in an inorganic compound do.

With these peculiarities in the chemical composition of organic bodies we may connect two other consequent facts: the first, that of the large number of different compounds that are formed out of comparatively few elements; the second, that of their great proneness to decomposition. For, it is a general rule, that the greater the number of equivalents or atoms of an element that enter into the formation of an atom of a compound, the less is the stability of that compound. Thus, for example, among the various oxides of lead and other metals, the least stable in their composition are those in which each equivalent has the largest number of equivalents of oxygen. So, water, composed of one equivalent of oxygen and one of hydrogen, is not changed by any slight force; but peroxyde of hydrogen, which has two equivalents of oxygen to one of hydrogen, is among the substances most easily decomposed.

The instability on this ground belonging to animal organic compounds is augmented, 1st, by their containing nitrogen, which, among all the elements, may be called the least decided in its affinities, that which maintains with least tenacity its combinations with other elements; and, 2dly, by the quantity of water which, in their natural mode of existence, is combined with them, and the presence of which furnishes a most favorable condition for the decomposition of nitrogenous compounds. Such, indeed, is the instability of animal compounds, arising from these several peculiarities in their constitution, that, in dead and moist animal matter, no more is requisite for the occurrence of decomposition than the presence of atmospheric air and a moderate temperature; conditions so commonly present that the decomposition of dead animal bodies appears to be, and is generally called, spontaneous. The modes of such decomposition vary according to the nature of the original compound, the temperature, the access of oxygen, the presence of microscopic organisms, and other circumstances, and constitute the several processes of decay and putrefaction; in the results of which processes the only general rule seems to be, that the several elements of the original compound finally unite to form those substances whose composition is, under the circumstances, most stable.[1]

[1] An interesting account of the nature of the so-called spontaneous decomposition of dead organic matter is given by Dr. Helmholtz (lxxx. 1843): for an abstract of the paper see xxv. 1843–4, p. 5. The experiments of Helmholtz show, that although the results of spontaneous decomposition are modified by the presence of infusorial organisms, yet these are not, as has

It is not known how far the process of decomposition which thus occurs in dead animal matter is imitated in the living body; but the facility of decomposition which it indicates may be considered in the study of those chemical changes which are constantly effected during life, tranquilly, and without the intervention of any such comparatively violent forces as are used in chemical art. The instability which organic compounds show when dead makes them amenable to the chemical forces exercised on them during life by the living tissues—forces inimitably gentle, so slight that their operation is not discernible by any effects besides those which they produce in the living body.

What has been said respecting the mode in which the elements are combined in the composition of animal matter refers only to the four essential elements. Little or nothing is known of the mode in which the incidental elements, or their compounds, are combined with the compounds formed of the essential elements; only it is probable that they are combined chemically and as necessary parts of the substances they contribute to form.

Of the *natural organic compounds* existing in the human body, some occur almost exclusively in particular tissues or fluids; as the coloring matter of the blood and other fluids, the fatty matter of the nervous organs, &c. But many exist in several different parts, and may, therefore, be now described in general terms.

They may be arranged in two classes, namely, the azotized or nitrogenous, and the non-azotized or non-nitrogenous principles.

The *non-azotized principles* include the several fatty, oily, or oleaginous substances, of which, in the human body, the most abundant are named margarine, elaine or oleine, stearine, cholestearine, and cerebrine.

The *fatty substances* are, nearly all, compounds of carbon, hydrogen, and oxygen. They burn with a bright flame, the proportion of oxygen being less than would be sufficient to form water with the hydrogen, or carbonic acid with the carbon, that they contain. They are all lighter than water, nearly all are fluid at the natural temperature of the body, all are insoluble in water, soluble in ether and boiling alcohol, and most of them crystallize when deposited from solution. They are nearly all of the kind named *fixed oils;* none of them is what is called a *drying oil, i. e.*, none so combines with oxygen as to form a resin-like varnish on the substance over which it is spread.

been supposed, essential to the occurrence of the process: their existence in large quantities in decomposing animal matters is due to the fact that such decomposition furnishes the most favorable conditions to their development and life. *Consult, also,* on this subject, Liebig, in the last edition of his *Animal Chemistry.*

The oily or fatty matter which, inclosed in minute cells, forms the essential part of the adipose or fatty tissue of the human body, and which is mingled in minute particles in many other tissues and fluids, consists of a mixture of margarine and oleine, the proportion of the former being the greater the higher the temperature at which the mixture congeals, and the firmer the mass is when congealed. The animal fats, or *suets*, that are firmer than human fat, contain also a substance named stearine, which remains solid at or near 130° F. Margarine congeals at about 120°, oleine at about 25°. Their mixture in human fat is a clear yellow oil, of which different specimens congeal at from 45° to 35° F. Margarine, when deposited from solution in alcohol, forms fine needle-shaped crystals; and microscopic tufts or balls of such crystals are often found in fat-cells after death, especially in the fat of diseased parts, and old people. According to Schultze, oleine, when acted upon by sulphuric acid and sugar, assumes the same violet-red color as ensues in bile when similarly tested, while the firmer fats are not thus affected, neither are the solid vegetable fats, although vegetable oils are colored like animal oleine (lix. 1850, p. 101).

Margarine and oleine, like all the fatty matters with which soaps may be made, and which are therefore named *saponifiable*, appear to consist of fatty acids combined with a base which is soluble in water.[1] When one of these fats is long boiled with an alkali, it is decomposed: the fatty acid, which is named margaric or oleic, according to the substance employed, unites with the alkali, forming a neutral soapy substance, margarate or oleate of soda, or potash, as the case may be; and the base of the fat, a sweet, syrupy substance named glycerine, remains. The fatty matter of human adipose tissue may therefore be regarded as a mixture of margarate and oleate of glycerine. Glycerine, moreover, is considered to be an hydrated oxide of a substance called Glyceryl; and margaric acid a compound of a substance named margaryl with oxygen. The formula for margarine is $C_{78}H_{75}O_{12}$; that for oleine $C_{84}H_{80}O_{13}$; that for glycerine $C_6H_7O_5 + HO$ (cxi. vol. i. p. 70).

Cholestarine, or *Cholesterine*, a fatty matter which does not melt below 278°, and is, therefore, always solid at the natural temperature of the body, may be obtained in small quantity from blood, bile, and nervous matter. It occurs abundantly in many biliary calculi; the pure white crystalline specimens of these concretions being formed of it almost exclusively. Minute rhomboidal scale-like crystals of it are also often found in morbid secretions, as in cysts, the puriform matter of softening and ulcerating tumors, &c. It is soluble in ether and boiling alcohol; but alkalies do not change

[1] See on this *subject Mulder (lxi.), Berzelius* (xxiv), and Redtenbacher *(x. Aug. 1847)*.

it: it is one of those fatty substances which are not saponifiable. Its formula is $C_{37}H_{38}O$ (lxxxii. vol. i. p. 83).

The *azotized* or *nitrogenous principles* in the human body include two chief classes of substances, namely, the gelatinous and the albuminous.

The *gelatinous substances* are contained in several of the tissues, especially those which serve a passive mechanical office in the economy; as the cellular or fibro-cellular tissue in all parts of the body, the tendons, ligaments, and other fibrous tissues, the cartilages and bones, the skin and serous membranes. These when boiled in water, yield a material, the solution of which remains liquid while it is hot, but becomes solid and jelly-like on cooling.

Two varieties of these substances are described, gelatine and chondrine: the latter being derived from cartilages, the former from all the other tissues enumerated above, and, in its purest state, from isinglass, which is the swimming-bladder of the sturgeon, and which, with the exception of about 7 per cent. of its weight, is wholly reducible into gelatine. The most characteristic property of gelatine is that already mentioned, of its solution being liquid when warm, and solidifying or setting when it cools. The temperature at which it becomes solid, the proportion of gelatine which must be in solution, and the firmness of the jelly when formed, are various, according to the source, the quantity, and the quality of the gelatine; but, as a general rule, one part of dry gelatine dissolved in 100 of water, will become solid when cooled to 60°. The solidified jelly may be again made liquid by heating it; and the transitions from the solid to the liquid state, by the alternate abstraction and addition of heat, may be repeated several times; but at length the gelatine is so far altered, and, apparently, oxidized by the process, that it no longer becomes solid on cooling. Gelatine in solutions too weak to solidify when cold, is distinguished by being precipitable with alcohol, creosote, tannic acid, and bichloride of mercury, and not precipitable with the ferrocyanide of potassium. The most delicate and striking of these tests is the tannic acid, which is conveniently supplied in an infusion of oak-bark or gall-nuts: it will detect one part of gelatine in 5000 of water; and if the solution of gelatine be strong it forms a singularly dense and heavy precipitate, which has been named tanno-gelatine, and is completely insoluble in water. Gelatine is also distinguished from albuminous substances by assuming a yellowish-brown, instead of a red color, when tested by sulphuric acid and sugar. (Schultze, lix. 1850, p. 102.)

When gelatine is boiled with caustic potash, or with sulphuric acid, it is decomposed, and among the products of its change are two substances named leucine and sugar of gelatine, of which the latter is remarkable for its similarity to the sugars produced from

vegetable substances, and for being susceptible of crystallization. (Simon, lxxxii. vol. i. p. 195, and Prout, xxi. p. 455; see also lix. 1850, p. 96.)

Among the varieties of gelatine derived from different tissues, and from the same sources at different ages, much diversity exists as to the firmness and other characters of the solid formed in the cooling of the solutions. The differences between isinglass, size, and glue in these respects are familiarly known, and afford good examples of the varieties called weak and strong, or low and high, gelatines. The differences are ascribed by Dr. Prout to the quantities of water combined in each case with the pure or anhydrous gelatine; and part of this water seems to be chemically combined with the gelatine, for no artificial addition of water to glue would give it the character of size, nor would any abstraction of water from isinglass or size convert it into the hard dry substance of glue. But such a change is effected in the gradual process of nutrition of the tissues; for, as a general rule, the tissues of an old animal yield a much firmer or stronger jelly than the corresponding parts of a young animal of the same species. A similar difference is observable in the leathers formed by the tanning of the skins of young and old animals; a fact which, together with the general similarity of the action of tannic acid upon skin and upon gelatine, makes it probable that gelatine is really (though some chemists hold the contrary) contained as such in the tissues, from which it is obtained by boiling. The analysis of dry gelatine yields C. 50.05, H. 6.47, N. 18.35, O. 25.13 parts in 100: its formula is stated as $C_{15}H_{10}N_4O_{14}$ (lx. p. 509).

Chondrine.—The variety of gelatine obtained from cartilages agrees with gelatine in that its solution in water solidifies on cooling, though less firmly, and is precipitable with alcohol, creosote, tannic acid, and bichloride of mercury. Like gelatine, also, it is distinguished from the albuminous substances by not being precipitable with ferrocyanide of potassium; but, unlike gelatine, it is precipitable with acetic and the mineral and other acids, and with the sulphate of alumina and potash, persulphate of iron and acetate of lead.

The *albuminous substances* are more highly or perfectly organic, i. e., are more different from inorganic bodies than are any of the substances yet considered, or, perhaps, any in the body. The chief of them are, albumen, fibrine, and caseine; but the last being found almost exclusively in milk, will be described with that fluid. Principles essentially similar to them all are found also in vegetables, especially in the sap and fruits. And substances much resembling, though not classed with, the albuminous, are horny matter and extractive matter. In addition to the chemical properties severally manifested by albumen, fibrine, and caseine, albuminous substances

generally are distinguished from the gelatinous by being changed into a violet-red color when treated with sulphuric acid and sugar, as in Pettenkofer's test for bile. These substances, indeed, undergo changes in color exactly similar to those undergone by bile when exposed to this test. (Schultze, lix. 1850, p. 101.) Millon has also found that albuminous substances assume an intense red color when treated with a solution of quicksilver dissolved in an equal weight of sulphuric acid, and four and a half parts of water. Gelatinous tissues, however, are similarly affected (xviii. vol. 28).

Albumen exists in some of the tissues of the body, especially the nervous, in the lymph, chyle, and blood, and in many morbid fluids, as the serous secretions of dropsy, pus, and others. In the human body it is most abundant, and most nearly pure, in the serum of the blood. In all the forms in which it naturally occurs, it is combined with about six per cent. of fatty matter, phosphate of lime, chloride of sodium, and other saline substances. Its most characteristic property is, that both in solution, and in the half solid state in which it exists in white-of-egg, it is coagulated by heat, and in thus becoming solid becomes insoluble in water. The temperature required for the coagulation of albumen is the higher the less the proportion of albumen in the solution submitted to heat. Serum and such strong solutions will begin to coagulate at from 150° to 170°, and these, when the heat is maintained, become almost wholly solid and opaque. But weak solutions require a much higher temperature, even that of boiling, for their coagulation, and either only become milky or opaline, or produce flocculi which are precipitated.[1]

Albumen, in the state in which it naturally occurs, appears to be but little soluble in pure water, but is soluble in water containing a small proportion of alkali.[2] In such solutions it is probably combined chemically with the alkali; it is precipitated from them by alcohol, ether, nitric, and other mineral acids (unless when they are very dilute), by ferrocyanide of potassium (if before or after adding it the alkali combined with the albumen be neutralized), by bichloride of mercury, acetate of lead, and most metallic salts. These precipitates are not merely solidified albumen, but compounds of albumen, with the acid or base added to it. In the former case the albumen takes the part of a base, as in nitrate of albumen; in the latter, it takes the part of an acid, as in albuminate of oxide of mercury, lead, &c. The precipitates with the metallic salts are soluble in an excess of albumen, and in solutions of chloride of

[1] For explanation of the conditions in which albumen in the urine and other fluids may not be coagulable by heat, see Dr. Bence Jones, lxxi. vol. xxvii. p. 288.

[2] On the mode of preparing albumen soluble in water without any addition, see Wurtz (xii. Oct. 1844).

sodium and other alkaline salts; and it is, probably, by these means that the salts of iron, mercury, and other metals, taken into the blood, remain dissolved in it.

Coagulated albumen, *i. e.*, albumen made solid with heat, is soluble in solutions of caustic alkali, and in acetic acid if it be long digested or boiled with it. With the aid of heat, also, strong hydrochloric acid dissolves albumen previously coagulated, and the solution has a beautiful purple or blue color.

The percentage composition of albumen of blood, according to the latest experiments of Mulder (lix. 1847, p. 83), is, carbon, 53.4; hydrogen, 7.1; nitrogen, 15.6; oxygen, 22.3; phosphorus, 0.3; sulphur, 1.3: its formula is not yet certainly known.

Fibrine exists, most abundantly, in solution in the blood and the more perfect portions of the lymph and chyle; and in the solid state, in some part of the tissue of voluntary muscles, and occasionally in minute particles in the blood. (R. D. Thomson, xvii. April, 1846.)

The characteristic property of fibrine is, that, in certain conditions (especially when the blood or other fluid containing it is taken from the living body), it separates from its solution, and spontaneously assumes the solid form, or coagulates.[1] It is on this that the coagulation of the blood (a process to be further described hereafter) depends. If a common clot of blood be pressed in fine linen while a stream of water flows upon it, the whole of the blood-color is gradually removed, and strings and various pieces remain of a soft, yet tough, elastic, and opaque-white substance, which consist of fibrine, impure with a mixture of fatty matter, lymph-corpuscles, shreds of the membranes of red blood-corpuscles, and some saline substances. Fibrine somewhat purer than this may be obtained by stirring blood while it coagulates, and collecting the shreds that attach themselves to the instrument, or by retarding the coagulation, and, while the red blood-corpuscles sink, collecting the fibrine unmixed with them. But in neither of these cases is the fibrine perfectly pure.

The nature of the process of coagulation will be considered in the account of the blood; it does not appear to be attended with any chemical change, but is comparable with the process in which fluids effused from the bloodvessels in nutrition or inflammation assume organic form and structure.

[1] A very small quantity of fibrine may be so dissolved in serous fluid that it will not spontaneously coagulate. The fluid of common hydrocele does not of itself coagulate; but, as Dr. Buchanan (lxxi. 1836, pp. 52 and 90, 1845, p. 617) has shown, if a piece of washed clot of blood, or of muscle, or some other animal tissue be placed in it, a filmy coagulum of fibrine will form and attach itself to the substance introduced. The film has the filamentous appearance of proper fibrine-clot, and is not mixed with corpuscles, as that of blood-clot is.

Chemically, fibrine and albumen cannot be distinguished. the changes, produced by various agents, in coagulated albu may be repeated with coagulated fibrine, with no greater differ of result than may be reasonably ascribed to the differences i mechanical properties of the two substances. Of such differe the principal are that fibrine immersed in acetic acid swells u becomes transparent like gelatine, while albumen undergo such apparent change; and that deutoxide of hydrogen is de posed when in contact with coagulated fibrine, but not with men.

Proteine.—It is the opinion of Mulder that animal albu fibrine, and caseine, and the corresponding substances derived vegetables, are all compounds of a substance which he has n proteine, and believes to be composed of the four essential elen alone. He assigns for its composition, carbon 55, hydrogen nitrogen 14.5, and oxygen 23.3 per cent.; and for its for $C_{36}H_{30}N_8O_{10}$. Proteine may be obtained by dissolving albu fibrine, or caseine in a heated solution of caustic potash (the l potassæ of the pharmacopœia will suffice), and adding to the tion enough acetic acid to neutralize it. The proteine, being luble in the neutral salts, is thus precipitated, in the form light grayish powdery-looking substance, whose reactions are similar to those of coagulated albumen.

Liebig, however, and Fleitmann (x. b. 61), deny the exis of any such substance as proteine, on the ground that what der so called and considered to be formed of none but the ess elements, always contains a certain quantity of sulphur, a albumen or other substance from which it was prepared This question is yet undetermined; for since Liebig publishe opinion, Mulder has repeated his own, and maintained though the proteine prepared as above described does contain phur, yet it is not in the form of elemental sulphur, but in of hypo-sulphurous acid. He believes albumen, fibrine, and principles of this group to be compounds of proteine with sulph and phosphamid, and that, in dissolving them in potash-lye, compounds are decomposed with water, ammonia being formed given off, while sulphurous and phosphorous acids combine the proteine (lix. 1847, p. 82). The question must, as ye thus left; but there seems sufficient probability in Mulder's vie justify the received use of the term *proteine compounds*, in s ing of the class, including fibrine, albumen, and others to v the name of albuminous compounds used to be applied.[1]

Horny Matter.—The substance of the horny tissues, incl the hair and nails (with whalebone, hoofs, and horns), prol

[1] For an account of the oxides and other compounds of proteine, s Essay of Mulder quoted above, or Canstatt's Jahresbericht for 1847,

consists, according to Mulder, of proteine with larger proportions of sulphamid than albumen and fibrine contain. Hair contains 10 per cent. and nails 6.8 per cent. of sulphamid. The composition of the latter is

C.	50.1	of the former	C.	49.9
H.	6.9		H.	6.4
N.	17.3		N.	17.1
O. with P.	22.5		O.	21.6
S.	3.2		S.	5.

The horny substances, to which Simon applies the name of keratine, are insoluble in water, alcohol, and ether; soluble in caustic alkalies, and sulphuric, nitric, and hydrochloric acids; and not precipitable from the solution in acids by ferrocyanide of potassium.

Mucus, in some of its forms, is related to these horny substances, consisting, in great part, of epithelium detached from the surface of mucous membrane, and floating in a peculiar clear and viscid fluid. But, under the name of mucus, several various substances are included, of which some are morbid albuminous secretions containing mucus and pus-corpuscles, and others consist of the fluid secretion variously altered, concentrated, or diluted. But the true chemical characters of this fluid are as yet incompletely known. It is generally alkaline, and, when the cells and other corpuscles mingled with it have subsided, is a pellucid fluid, containing, according to Berzelius, 5.33 per cent. of proper mucous matter. This is very little soluble in water; more soluble in water slightly alkaline, and from this solution is precipitated by alcohol, acetic, nitric, sulphuric, and hydrochloric acids. An excess of the last three acids redissolves the precipitates they severally throw down; and, in the acid solution thus formed, ferrocyanide of potassium produces no precipitate. According to Scherer (x. b. 57), pure mucus, cleared of epithelium, and subtracting 4.1 per cent. of saline matter, contains carbon 52.17, hydrogen 7.01, nitrogen 12.64, oxygen 28.18.

Extractive Matters.—Under this name are included substances of mixed and uncertain composition, which form the residue of animal matter when, from almost any of the fluids or solids of the body, the albuminous, gelatinous, and fatty principles have been removed. The remaining animal matter is mixed with various salts, such as lactates, chlorides, and phosphates, and is divisible into two principal portions, of which one is soluble in water alone, the other in alcohol.

Doubtless there are in these substances many distinct compounds, of which some exist ready-formed in the body, and some are formed in the changes to which the previous chemical examinations have given rise. Some of these substances have received specific names, according to their most striking characters, as osmazome and

zomidine, on which the principal odor and taste of cooked made appear to depend; or according to their source, as ptyaline and phymatine, from the saliva and pancreatic fluid; and part of the extractive matter of the blood appears to be a compound of proteine. (Ludwig, x. 1845.) But the true composition, origin, and nature of all these substances are unknown. Kreatine and kreatinine, two principles which used to be included among the extractive matters of muscular tissue, have been lately studied by Liebig (liv.), who has found them also in the urine, and has thus given additional probability to the suggestion of Berzelius, that the extractive matters are generally the products of the chemical changes that take place in the natural waste and degeneration of the tissues, and are the substances that are to be separated from the tissues for excretion.

Such are the chief substances of which the human body is composed. They are formed mainly of the four essential elements, and exhibit all those characters which have been mentioned as peculiar to organic bodies; but with the exception of the fatty matters, and perhaps proteine, all appear to contain, besides the four elements, other elements, or even compound substances, such as phosphate of lime, chloride of sodium, or other salts. And all the fluids and tissues of the body appear to consist, chemically speaking, of mixtures of several of these principles, together with saline matters. Thus, for example, a piece of muscular flesh would yield fibrine, albumen, gelatine, fatty matters, salts of soda, potash, lime, magnesia, iron, and other substances which appear passing from the organic towards the inorganic states, as kreatine and others. This mixture of substances may be explained in some measure by the existence of many different structures or tissues in the muscles; the gelatine may be referred principally to the cellular tissue between the fibres, the fatty matter to the adipose tissue in the same position, and part of the albumen to the blood and the fluid by which the tissue is kept moist. But, beyond these general statements, little can be said of the mode in which the chemical compounds are united to form an organized structure; or of how, in any organic body, the several inorganic and incidental substances are combined with those that are organic and essential. It must suffice, therefore, to mention the several parts in which each of the incidental elements and of their principal compounds occur.

Sulphur[1] is probably, next to the essential ones, the most nearly constant element in organic compounds. It exists in albumen, fibrine, caseine, and gelatine, combined in all these, probably in

[1] On the quantity of sulphur in different animal substances, see Ruling *and others* in Liebig's Annalen der Chemie und Pharmacie, Bd. lviii. and *Canstatt's Jahresbericht* for 1846, p. 90.

the elemental state, with the other elements. In largest proportion it is found in taurine, one of the products of the decomposition of biliary matter, and in the morbid product, cystic oxide: of both these it constitutes about 25 per cent. Among the tissues, and independent of the compounds above named as containing it, sulphur is most abundant in the hair, cuticle, nails, and other horny tissues, and, according to Lassaigne (lv. Aug. 22, 1843), in fibrous and mucous membranes. Of the compounds of sulphur none are known to exist naturally, except the sulphocyanide of potassium in saliva, and the alkaline sulphates in the urine and sweat. The acid of the sulphates found in the ashes of other animal substances are formed during the burning, through the elemental sulphur combining with oxygen.

Phosphorus is found together with sulphur, and probably similarly combined as an element, in albumen and fibrine, but not in caseine. It exists also in some tissues, especially in the substance of the brain, from which two fatty acids, containing phosphorus and named oleo-phosphoric and cerebric acid, have been obtained; but, most abundantly, it occurs as phosphoric acid in combination with alkaline and earthy bases—as in the tribasic phosphate of soda in the blood and saliva, the super-phosphates of the muscles and urine, the basic phosphate of lime and magnesia in the bones and teeth. Such phosphates are also found in the ashes of nearly all burnt animal substances, even in tissues so simple that one must assume the phosphate to be a necessary constituent of the substance of the primary cell; for it is probable that these phosphates exist in the tissues ready formed, as they do in caseine, and that they are not, like the sulphates, found in the ashes of animal matters, produced in the combustion.

Silicon.—A very small quantity of silica exists, according to Berzelius, in the urine, and, according to Henneberg (x. Bd. 41) and E. Millon (xviii. 1848), in the blood. Traces of it have also been found in bones by V. Bibra, in hair by Van Laer, and in some other parts of the body (lxv. p. 65).

Chlorine is abundant in combination with sodium, potassium, ammonium, and other bases in all parts, fluids as well as solid, of the body. Chloride of sodium (common salt) is, indeed, probably the most abundant of all the inorganic compounds in organized bodies. It is also not improbable that chlorine may exist in the gastric fluid in the form of hydrochloric acid, either free or in combination with an organic principle. (Schmidt, lix. 1847, p. 102.)

Fluorine.—After the observations of Berzelius had been much questioned on which the existence of minute quantities of fluoride of calcium in the bones, teeth, and urine was admitted, they have been *fully confirmed by Dr. Daubeny and Mr.* Middleton (lxiii. vol. *ii. pp. 97, 134), and more recently by* Von Bibra (lxiv.). The salt

is found in the ashes of all bones and teeth; and increased in quantity in fossil bones.

Potassium and *sodium* are constituents of the blood and all the fluids, in various quantities and proportions. They exist in the forms of chlorides, sulphates, and phosphates, and probably, also in combination with albumen, or certain organic acids. Liebig, in his work on the Chemistry of Food, has shown that the juice expressed from muscular flesh always contains a much larger proportion of potash-salts than of soda-salts; while in the blood and other fluids, except the milk, the latter salts always preponderate over the former; so that, for example, for every 100 parts of soda-salts in the blood of the chicken, ox, and horse, there are only 40.8, 5.9, and 9.5 parts of potash-salts; but for every 100 parts of soda-salts in their muscles there are 381, 279, and 285 parts of potash-salts.

Calcium.—The salts of lime (oxide of calcium) are by far the most abundant of the earthy salts found in the human body. They exist in the lymph, chyle, and blood in combination with phosphoric acid, the phosphate of lime being probably held in solution by the presence of phosphate of soda. Perhaps no tissue is wholly void of phosphate of lime; but its especial seats are the bones and teeth, in which, together with carbonate and fluate of lime, it is deposited in minute granules, in a peculiar compound, named bone-earth, and containing 51.55 parts of lime, and 48.45 of phosphoric acid Phosphate of lime, probably the tribasic phosphate, is also found in the saliva, milk, bile, and most other secretions, and superphosphate in the urine, and probably in the gastric fluid. (Blondlot, xvi.)

Magnesium appears to be always associated with calcium, and probably exists in the same forms as it; but its proportion is always much smaller, except in the juice expressed from muscles, in the ashes of which magnesia preponderates over lime. (Liebig, liv.)

Iron.—The especial place of iron is in the hæmatosine, the coloring-matter of the blood, of which a further account will be given with the chemistry of the blood. Peroxide of iron is found, in very small quantities, in the ashes of bones, muscles, and many tissues, and of lymph and chyle, albumen of serum, fibrine, bile, and other fluids; and a salt of iron, probably a phosphate, exists in considerable quantity in the hair, black pigment, and other deeply colored epithelial or horny substances.

Manganesium.—Vauquelin believed he found a trace of the peroxide of this metal in the ashes of hair and bones; but in the more accurate analysis of the former substance by V. Laer, and of the latter by V. Bibra, no mention of manganesium is made. It has been detected in gall-stones (lxxxii. vol. i. p. 4). According to M. E. Millon (xviii. 1848), it exists naturally in blood.

Aluminium also is stated (Henle, xxxvii. p. 4) to exist in the ashes of hair, bones, and enamel; but neither V. Laer nor V. Bibra mention it.

Copper.—After long disputes, the general existence of copper in the human liver may be regarded as proved by the experiments of Orfila, Heller, and others. It exists in especially large quantity in dark biliary calculi, and we may probably assume that it does not enter into the proper permanent substance of the liver, but is contained in the bile, within the bile-cells and ducts, and is destined with it to be excreted. It is true, that Harless and V. Bibra have found it constantly present in the blood, as well as in the liver, of many mollusca and fish: and that in their blood it takes the place of some proportion of the iron contained in the blood of other species, and may be regarded as a normal, necessary constituent; yet, it seems most likely that, in the human body, both copper, manganesium, and aluminium should be regarded as *accidental elements*, which, being taken in minute quantities with the food, and not excreted at once with the feces, are absorbed and deposited in some tissue or organ, of which, however, they form no necessary part. In the same manner arsenic and lead, being absorbed, may be deposited in the liver and other parts. This view is confirmed by the fact observed by Heller, that although copper is frequently present in the bile of adults, yet it is never found in that of infants (ix. vol. ii. p. 321). The researches of Cattanei di Momo also seemed to prove that neither copper nor lead exists in the bodies of new-born children or infants (xxv. 1843–4, p. 3).

CHAPTER II.

STRUCTURAL COMPOSITION OF THE HUMAN BODY.

The component substances of the body are commonly divided into fluids and solids.

The *fluids* are, 1st, *formative fluids*, from which are derived the materials for the formation of the solid tissues; and, 2d, *secreted fluids*, which are separated from the tissues and the blood, through, speaking generally, the operation of special organs, such as cells arranged in glands or membranes.

So little can be said that would apply to all the members of either of these classes of the fluids, that a general description of them would be useless; they will therefore be considered in their several more appropriate places.—[See chapters on Blood, Lymph, Chyle, the several Secretions, &c.]

Among the *solids* of the body, some appear, even with the help of the best microscopic apparatus, perfectly uniform and simple: they show no trace of structure, *i. e.*, of being composed of definitely arranged dissimilar parts. These are named *simple, structureless*, or *amorphous solids*. Such are the apparently structureless mass composing the albumen of eggs, and the substance called *cytoblastema*, or *formative substance*, in which the nuclei and cells are imbedded in many tissues in progress of development. Such also is the simple membrane which forms the walls of most primary cells, of the finest capillary bloodvessels and gland-ducts, and of the sarcolemma of muscular fibre; and such the membrane enveloping the vitreous humor of the eye. Such also, having a dimly granular appearance, but no really granular structure, is the intercellular substance of the most perfect cartilage.

In the solids which present determinate structure, certain primary forms may be distinguished, which, by their various modifications and modes of combination, make up the tissues and organs of the body. Such are: 1. *Granules*, or *molecules*, the simplest and minutest of the primary forms. They are particles of various size, from immeasurable minuteness to the 1-10000th of an inch in diameter; of various and generally uncertain composition, but usually so affecting light transmitted through them, that at different focal distances their centre, or margin, or whole substance, appears black. From this character, as well as from their low specific gravity (for in microscopic examinations they always appear lighter than water), and from their solubility in ether when they can be favorably tested, it is probable that most granules are formed of fatty or oily matter; or, since they do not coalesce as minute drops of oil would, that they are particles of oil coated over with albumen deposited on them from the fluid in which they float. (*See* Ascherson, lxxx. 1848.) In any fluid that is not too viscid, they exhibit the phenomenon of *molecular motion*, shaking and vibrating incessantly, and sometimes moving through the fluid, under the influence of some unknown force.

Granules are either *free*, as in milk, chyle, milky serum, yelk-substance, and most tissues containing cells with granules; or *inclosed*, as are the granules in nerve-corpuscles, gland-cells, and epithelium-cells, the pigment granules in the pigmentum nigrum and medullary substance of the hair; or *imbedded*, as are the granules of phosphate and carbonate of lime in bones and teeth.

2. *Nuclei*, or *cytoblasts*, appear to be the simplest elementary structures, next to granules. They were thus named in accordance with the hypothesis that they are always connected with cells, or tissues formed from cells, and that in the development of cells, each nucleus is the germ or centre around which the cell is formed. The hypothesis is only partially true, but the terms based on it are

too familiarly accepted to make it advisable to change them till some more exact and comprehensive hypothesis is formed.

Of the corpuscles called nuclei, or cytoblasts, the greater part are minute cellules, or vesicles, with walls formed of simple membrane, inclosing a colorless pellucid fluid, and often one or more particles, like minute granules, called *nucleus-corpuscles*, or *nucleoli*. Such vesicular nuclei, without nucleoli, are those of the blood-corpuscles of oviparous vertebrate animals (figs. 1 and 2); and such,

Fig. 1.

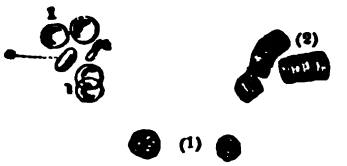


Fig. 2.

Fig. 1. Corpuscles of human blood, magnified about 500 diameters.—(1) Single particles. 1, 1. Their flattened face. 2, A particle seen edgewise. (2) Aggregation of particles in a columnar form.

Fig. 2. Red particles of the blood of the common fowl. *a*, Ordinary appearance when the flat surface is turned towards the eye; *b*, appearance which is sometimes presented by the particle when in the same position, and which suggests the idea of a furrow surrounding the central nucleus; *c*, *d*, different appearances of the particles when seen edgewise.

with nucleoli, are those of epithelium-cells and pigment-cells. But some nuclei appear to be formed of an aggregate of granules imbedded in a pellucid substance, as, for example, the nuclei of the lymph- and chyle-corpuscles.

The composition of the nucleus is uncertain. One of its most general characters, and the most useful in microscopic examinations is, that it is neither dissolved nor made transparent by acetic acid, but acquires, when that fluid is in contact with it, a darker and more distinct outline. On this account, Kölliker (lxxxiv. pp. 144–5) supposes the wall of the nucleus to be composed of a proteine-compound named *pyine*; its contents he also considers to be albumen, and the nucleoli fatty matter; but there is not sufficient evidence for these views.

Nuclei may be either *free* or *attached*. *Free nuclei* are such as either float in fluid, like those in the gastric juice, which appear to be derived from the secreting cells of the gastric glands, or lie loosely imbedded in solid substance, as in the gray matter of the brain and spinal cord, and most abundantly in some quickly-growing tumors.

Attached nuclei are either closely imbedded in homogeneous pellucid substance, as in rudimental cellular tissue; or are fixed on the surface of fibres, as on those of organic muscle and organic nerve-

fibres (fig. 3); or are inclosed in cells, or in tissues formed by the extension or junction of cells. Nuclei inclosed in cells appear to be attached to the inner surface of the cell wall, projecting into the cavity. Their position in relation to the centre or axis of the cell is uncertain; often, when the cell lies on a flat or broad surface, they appear central, as in blood-corpuscles, epithelium-cells, whether tesselated or cylindrical; but, perhaps, more often their position has no regular relation to the centre of the cell. In most instances, each cell contains only a single nucleus; but in cartilage, especially when it is growing or ossifying, two or more nuclei in each cell are common; and the development of new cells is often effected by a division or multiplication of nuclei in the cavity of a parent cell; as in blood-cells, the germinal vesicle, and others.

Fig. 3.

Fibres of unstriped muscle: *c*. In their natural state. *a*. Treated with acetic acid, showing the corpuscles. *b*. Corpuscles, or nuclei, detached, showing their various appearances.

When cells extend and coalesce, so that their walls form tubes or sheaths, the nuclei commonly remain attached to the inner surface of the wall. Thus they are seen imbedded in the walls of the minutest capillary bloodvessels of, for example, the retina and brain; in the sarcolemma of transversely striated muscular fibres; and in minute gland-tubes. In such cases their arrangement may be irregular, as in the capillaries; or regular, as in the single or alternating double rows of nuclei in different examples of the muscular fibre.

Nuclei are most commonly oval or round, and do not generally conform themselves to the diverse shapes that the cells assume; they are, altogether, less variable elements, even in regard to size, than the cells are; of which fact one may see a good example in the uniformity of the nuclei in cells so multiform as those of epithelium. But sometimes they appear to be developed into filaments, elongating themselves and becoming solid, and uniting end to end for greater length, or by lateral branches to form a network. So, according to Henle (xxxvii. p. 194), are formed the *filaments of the striated* and fenestrated coats of arteries, and the *yellow or elastic filaments* of cellular tissue, and with organic muscu-

pecially in the walls of arteries. The filaments of the
stance of hair, and the seminal filaments, or spermato-
ar to be also elongated and divided nuclei.

, *Primary cells*, or *Elementary cells*, are vesicles or scales
verage size than nuclei, but, like them, composed, in the
ite, of membranous cell-walls, with, usually, liquid con-
generally round or oval.

l-wall never presents any appearance of structure: it
metimes to be a proteine-substance, as in blood-cells;
a horny matter, as in thick and dried cuticle. In almost
(the dry cells of horny tissue, perhaps, alone excepted)
all is made transparent by acetic acid, which also pene-
ugh it and distends it, so that it can hardly be discerned.
ch cases the cell-wall is usually not dissolved; it may be
nto view again by nearly neutralizing the acid with soda

e instances, the most developed state of a cell is that in
as no nucleus, as in the mammalian blood-corpuscles, in
will be described, the substance of the nucleus of the
chyle-corpuscle is gradually all appropriated and changed
ntents of the blood-corpuscle. But, in other instances,
in old cells, as in those of the nails, the outer layers of
, and the adipose tissue, the nucleus may disappear, wast-
; and this is, probably, always a sign of degeneration of
, for a similar wasting of nuclei is commonly observed in
in the state of fatty degeneration.

he exceptions just mentioned, all the cells of the human
ear to contain nuclei. Sometimes the nucleus nearly
avity of the cell, as in lymph- and chyle-corpuscles, in
e cell-wall lies so close round the nucleus, that it can
seen till it is raised up by water or acetic acid insinuat-
between it and the nucleus; and such is the proportion
he nucleus and cell in young epidermis-cells; but more
nucleus has a diameter from one-fourth to one-tenth less
of the cell.

nplest *shape* of cells, and that which is probably the nor-
of the primary cell, is oval or spheroidal, as in cartilage-
lymph-corpuscles; but in many instances they are flat-
l discoid, as in the blood-corpuscles, or scale-like, as in
and tesselated epithelium. By mutual pressure they may
any-sided, as the pigment-cells of the choroidal pigmen-
um and in close-textured adipose tissue; they may assume
or cylindriform or prismatic shape, as in the varieties of
pithelium and the *enamel-tubes;* or be caudate, as in
dies in the spleen; they may send out exceedingly fine
in the form of vibratile cilia, or larger processes, with

which they become stellate, or variously caudate, as in the large nerve- or ganglion-corpuscles, and the epithelium of the choroid plexuses.

The *contents* of cells, including under this term all but their nuclei, are almost infinitely various, according to the position, office, and age of the cell. In adipose tissue, they are the oily matter of the fat, the mixture of margarine and oleine; in gland-cells, the contents are the proper substance of the secretion, bile, semen, &c., as the case may be; in pigment-cells, they are the pigment-granules that give the color; and in the numerous instances in which the cell-contents can be neither seen because they are pellucid, nor tested because of their minute quantity, they are yet, probably, peculiar in each tissue, and constitute the greater part of the proper substance of each. Commonly, when the contents are pellucid, they contain granules which float in them; and when water is added and the contents are diluted, the granules display an active molecular movement within the cavity of the cell. Such a movement may be seen by adding water to mucus- or pus-corpuscles, or to those of lymph. In a few cases the whole cavity of the cell is filled with granules: it is so in yelk-cells and milk-corpuscles, in the large diseased corpuscles often found among the products of inflammation, and in some cells when they are the seat of extreme fatty degeneration. The peculiar contents of cells may be often observed to accumulate first around or directly over the nuclei, as in the cells of black pigment, in those of melanotic tumors, and in those of the liver during retention of bile.

Intercellular substance is the material in which, in certain tissues, the cells are imbedded. Its quantity is very variable. In the finer epithelia, especially the columnar epithelium on the mucous membrane of the intestines, it can be just seen filling the interstices of the close-set cells; here it has no appearance of structure. In cartilage and bone it forms a large portion of the whole substance of the tissue, and is either homogeneous and finely granular, or osseous, or, as in fibro-cartilage, resembles tough tendinous tissue. In some cases, the cells are very loosely connected with the intercellular substance, and may be nearly separated from it, as in fibro-cartilage; but in some their walls seem amalgamated with it.

The foregoing may be regarded as the simplest, and the nearest to the primary, forms assumed in the organization of animal matter; as the states into which it passes in becoming a solid tissue living or capable of life. By the further development of tissue thus far organized, according to rules which will be hereafter described, higher or secondary forms are produced, which it will be sufficient in this place merely to enumerate. Such are, 4, *Filaments, or fibrils.*—Threads of exceeding fineness, from 1-20000th of *an inch upwards.* Such filaments are either cylindriform, as are

those of the striated muscular (figs. 4 and 5), and the fibro-cellular or areolar tissue (figs. 6 and 7); or flattened, as are those of the organic muscles (fig. 3), the common elastic tissues (figs. 8 and 9), and the finer variety of the same tissue, which is commonly associated with the proper white filaments of the fibro-cellular tissue. Filaments usually lie in parallel fasciculi, as in muscular and tendinous tissues; but in some instances are matted or reticular, with branches and intercommunications, as are the filaments of the middle coat, and of the longitudinally-fibrous coat of arteries; and in other instances, are spirally wound, or very tortuous, as in the common fibro-cellular tissue.

Fig. 4. Fig. 5.

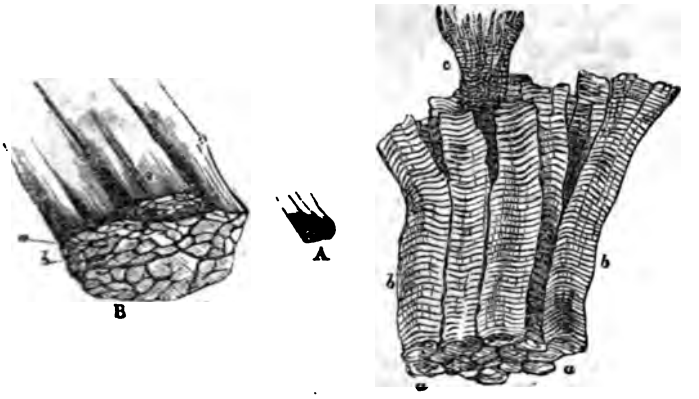


Fig. 4. Muscular fibre of animal life (magnified 5 diameters). A. Small portion, natural size. B. Same, magnified 5 diameters, of larger and smaller fasciculi, seen in transverse section.

Fig. 5. Portion of broken muscular fibre of animal life (magnified about 700 diameters.)

5. *Fibres*, in the instances to which the name is commonly applied, are larger than filaments or fibrils, but are by no essential general character distinguished from them. The flattened band-like fibres of the coarser varieties of organic muscles and elastic tissue are the simplest examples of this form; the toothed fibres of the crystalline lens are more complex; and more compound, so as hardly to permit of being classed as elementary forms, are the striated muscular fibres, which consist of bundles of filaments inclosed in separate membranous sheaths, and the cerebro-spinal nerve-fibres in which similar sheaths inclose apparently two varieties of nerve-substance.

6. *Tubules are formed of simple membrane*, such as the minute *capillary lymph- and bloodvessels, the investing* sheaths of striated

muscular and cerebro-spinal nerve-fibres, and the basement-membrane or proper wall of the fine ducts of secreting glands.

Fig. 6.

Fig. 7.

Fig. 6. Fasciculi and fibres of cellular tissue.—The two elements of Areolar tissue, in their natural relations to one another: 1, the white fibrous element, with cell-nuclei, 9, sparingly visible in it; 2, the yellow fibrous element, showing the branching or anastomosing character of its fibrillæ; 3, fibrillæ of the yellow element, far finer than the rest, but having a similar curly character, 8, nucleolated cell-nuclei, often seen apparently loose.—From the areolar tissue under the pectoral muscle, magnified 320 diameters.

Fig. 7. Development of the Areolar tissue (white fibrous element): 4, nucleated cells, of a rounded form; 5, 6, 7, the same, elongated in different degrees, and branching. At 7, the elongated extremities have joined others, and are already assuming a distinctly fibrous tissue character. (After Schwann.)

Most of the tissues which are composed of these primary structures will be briefly described in future chapters, and in connection with the physiology of the organs that they help to form. The insertion of a system of general anatomy would not further the purpose of this work; and would be superfluous while the student has access to such admirable works devoted to the subject as the Introduction to Quain's Anatomy by Dr. Sharpey, the Physiological Anatomy of Dr. Todd and Mr. Bowman, the Microscopic *Anatomy of the Human* Body by Mr. Hassall, and the various articles

on the tissues published in the Cyclopædia of Anatomy and Physiology.

Fig. 8.

Fig. 9.

Fig. 8. Fibres of elastic tissue from the ligamentum flavum of the vertebræ. (Magnified 320 diameters.)

Fig. 9. Portion of white fibrous tissue, magnified 320 diameters. 1, 2. Straight appearance of the tissue when stretched; 3, 4, 5. Various wavy appearances which the tissue exhibits when not stretched.

CHAPTER III.

VITAL PROPERTIES OF THE ORGANS AND TISSUES OF THE HUMAN BODY.

Some of the actions observed in living bodies indicate the operation of other properties and forces besides those which can be referred to the chemical and mechanical constitution of organized substances. These properties being the sources of phenomena which are peculiar to living beings, are named *vital properties;* the forces issuing from them, *vital forces;* the acts in which they are expressed, such as those enumerated at pp. 13, 14, are *vital acts* or *vital processes;* and the state in which these processes are displayed is *life.*

1. The *most general, perhaps an* universal, property of living *bodies, is that which is manifested* in the ability to form them-

selves out of materials dissimilar from them; as when, for example, the ovule develops itself from the nutriment of the fluids of the parent—or when a plant, or any part of one, grows by appropriating the elements of water, carbonic acid, and ammonia—or when an animal subsists on vegetables, and its blood and various organs are formed from the materials of its food. The force which is manifested in these acts is termed *formative force* (assimilative, or plastic force); and the processes effected by it are named *assimilative, nutritive,* or *formative processes.*

This power of self-formation from dissimilar materials, which appears to be wholly peculiar to living bodies, and without which, probably, none exists, manifests itself in three modes, which, though they bear different names, yet probably are only three expressions of one force operating in different conditions: they are *development, growth,* and *assimilation,* or *maintenance.*

Development is the process by which each tissue or organ of a living body is first formed; or by which one, being already incompletely formed, is so changed in shape and composition as to be fitted for a function of a higher kind; or, finally, is advanced to the state in which it exists in the most perfect condition of the species.

Growth, which commonly concurs with development and continues after it, is, properly, mere increase of a part by the insertion or superaddition of materials similar to those of which it already consists. In growth, properly so called, no change of form or composition occurs: parts only increase in weight, and, usually, in size; and if they acquire more power, it is only more power of the same kind as that which they before enjoyed.

In assimilation, or self-maintenance, living bodies preserve their condition notwithstanding the changes to which they are liable through the influence of external forces and their own natural decay; and the stability of composition which they thus display is effected by the continual formation of new particles in the place of those that are impaired and removed.

The modes in which these three manifestations of formative power are accomplished will be considered hereafter, especially in the chapters on NUTRITION, SECRETION, and DEVELOPMENT. From these it will appear that the most general, and one of the simplest, modes is in the formation and further development of nucleated cells. The nucleated cell is the form towards which organizing matter most commonly tends, in which it often rests, and through which it usually proceeds in its further developments. In nucleated cells, also, are the best examples of inherent formative power, which, not being consumed in the formation of the cells, remains operative in them, changing them and their contents, and influencing the surrounding or intercellular substance in which they are deposited. Thus, whether it be for the preparation of materials from food which

may serve to the maintenance of the body, or for the construction of the several tissues, or for the formation or temporary storing-up of the materials that are to be removed from the body as refuse, in all these, and in nearly all instances of them, the end is attained by or with the help of the formation, continued energy, or dissolution of nucleated cells.

The property to which is referred the formative power of living beings, or living parts, is, however, no simple property, such as the "attraction" of mechanical science, or the "affinity" of chemistry. These manifest themselves in acts so simple and almost uniform, that the hypothesis which assumes the existence of such properties supplies at once the language in which their laws of action may be enunciated. But in the simplest exercise of living formative power, even in that which accomplishes the formation of a cell, there is evidence of the operation of many forces. Mechanical force is shown in the determination of the position, shape, and relations of the cell; chemical force, in the determination of the composition of its walls and contents: and with these, or as if directing them, that vital force, different from them and from all other known physical forces, is in operation, by virtue of which the cell acquires all the properties that characterize the species or organ to which it is attached, and becomes capable of taking part in vital processes —even in such processes as those in which itself originated.

Thus the vital formative force seems not to oppose or exclude, but to include and direct the physical forces that issue from the mere matter of the organic body. It may, therefore, be believed that every vital act is accompanied with physical changes in the active matter; but there is no sufficient evidence that such changes ever wholly constitute or make up any of those that are commonly called vital acts. In all those acts or processes some force is exercised peculiar to the state of life, and as different from all recognized physical forces as they are different from one another. We cannot tell how much in each act of the living body is physical, and how much depends on the peculiar vital force. The advancing knowledge of the physical sciences does, indeed, prove every year that effects, which used to be ascribed to vital forces are due to the operation of the forces of chemistry and mechanics; and it may be observed, generally, that the substances in which the processes of organic life are most actively carried on are those whose chemical composition is most remote from that of inorganic matter. Still, many things yet remain, observed only in the living body, so completely dependent on the maintenance of the whole state of life, and so different from what physical forces ever accomplish in dead matter, that we cannot refer them to the operation of those forces. Any hypothesis *which would abolish the idea* of vital formative force,

would be much less reasonable and useful than that which admits it; indeed, unless we admit the existence of such a force in the processes of organic life, and adopt the language which the hypothesis suggests, it is hardly possible to express the ordinary facts of physiology.

2. *Contractility* may be reckoned a second vital property. It consists in the power which certain tissues have, during life, of contracting or shortening themselves in a peculiar manner. Such contractility is usually and best observed in fibrous tissues, as in muscles and some kinds of fibro-cellular tissue; but it may be seen, also, in cells and collections of them, as in the muscles of embryos, while they yet consist of cells, and before any fibres are developed in them.

The peculiar contraction of muscular and other organic tissues differs from the contraction of which dead and inorganic matter is capable, both in its modes and in the conditions that give rise to it. The modes of contraction will be described hereafter: the conditions are not only such previous elongation as would be followed by contraction in any elastic body, but various slight changes, such as those produced by the contact of foreign matters, variations of temperature, electricity, &c. These, and whatever will give rise to the peculiar contractions in the organic tissues, are called *stimuli*.

That which most characterizes the contractility of animal tissues is, that the contraction may be excited by the application of a stimulus to the nerves that ramify in them; and, indeed, it is generally through the nerves that the stimulus which produces a contraction is conveyed. In the chapter on the MUSCLES, it will be shown that the property of contractility is inherent in the tissues that contract, and is essentially independent of their nerves; so that contraction *may* take place without the co-operation of the nerves. Therefore, the whole property of *irritability*, including both the capacity of receiving a direct stimulus and the power of contracting in consequence thereof, may be ascribed to the muscles and other contractile tissues. But, in the ordinary conditions of life, the nerves may be said to be necessary to contractions, because, in these conditions, it is only through the medium of nerves that a stimulus is applied to the contractile tissues, and when the nerves are destroyed contractions do not naturally ensue.

The modes in which stimuli are applied to, and their effects conveyed along, nerves to the contractile parts, will be described in the chapter on the NERVOUS SYSTEM. One mode is essentially characteristic of animals; that, namely, wherein the contractile tissues are made to act by a Mind, an *Anima;* which, having *knowledge of the existence* of the body, consciousness of power, and

will to exercise it, acts on the nervous system,[1] and through it on the contractile tissues: thus voluntary motion is produced.

3. The *power of conducting* or *transmitting* stimuli or impressions which, in the foregoing paragraphs, has been ascribed to the nerves, constitutes another peculiar vital property. It belongs to the nervous system alone, and may be said to consist in this—that the state, or change, which is produced in the fibre of a nerve by the application of a stimulus of any kind, may be propagated through the whole length of the fibre, so that every part thereof shall, with immeasurable rapidity, be brought into the same state as the part first stimulated. Thus the stimulus, or rather the change or *impression* produced by it, is said to be *conducted* by the nerve; in the same way as it is said electricity is conducted along a wire, although at the instant of contact with the source of electricity the whole wire becomes at once electric.

A peculiar force is generated by the change thus produced in nerves, the effect of which force, when the nerve conveys it to a muscle, is shown by the muscle contracting with a force which, other things being equal, is directly proportionate to the intensity of the stimulus. The same force, generated by stimulating nerves, may also be shown by changes in organic processes; as when secretions are augmented, diminished, or altered, in states of nervous excitement. The force thus developed in the nerves has been named *vis nervosa*, but there is an objection to the use of the term, since some appear to think that force is exercised only when the conduction takes place towards muscles, and that in that case the force itself is in some way transferred from the nerves to the muscle. But a safer hypothesis appears to be that which holds that a peculiar force is generated whenever a nerve is stimulated; and which ascribes to all nerves alike the power of conducting impressions; *i. e.*, of propagating the changes produced by stimuli, and the force issuing therefrom. Adopting this hypothesis, we may believe that the different consequences of such conducted force depend on the various connections of the conducting nerve-fibres with the nervous centres and contractile parts, on the nature and strength of the stimulus, and on other circumstances external to the nerves.

When an impression is conveyed from any part of the body, along a nerve, to the brain, the mind may take cognizance of it: what the mind thus becomes conscious of is called a sensation; and the act of the mind noticing it, perception; and all parts through

[1] It does so, at least, in all animals in which a nervous system can be demonstrated. In those in which none has been yet seen, it must be doubtful whether the mind can directly influence the contractile tissues, or whether some nervous material exists which we cannot discover, but through which the mind of the animal can act.

the nerves of which such sensations may be derived are called sensible or sensitive parts. But in the use of the latter terms it must be remembered that they mean only that certain parts are capable of giving rise to sensations. The mind alone is sentient and percipient; neither tissues, nerves, nor brain, could of themselves, or from any property or change of which they are capable, become in any sense conscious of their condition.

Such appear to be the peculiar properties of living animal matter. It is all capable of self-formation, and the various modes of formation constitute the principal functions of the organic life of the animal. Some of the living tissues are, also, capable of peculiarly contracting; and the nervous tissue is capable of peculiarly conducting the changes or impressions made on it by certain stimuli. These two properties, in their various modifications, are exercised especially in the animal life, and it is by means of these that the mind becomes cognizant of the condition of the body, and through it, of some of the properties of things that act on it, as well as able to will the movements of its several parts.

CHAPTER IV.

THE BLOOD.

THE processes enumerated in the first division of the phenomena of Organic Life have their end or purpose in the formation, movement, and purification of the blood. The physiology of the blood must, therefore, precede the consideration of these subservient processes.

Wherever blood can be seen as it flows in the vessels of a living part, it appears a colorless fluid, containing minute particles, the greater part of which are red, and give the blood its color. The fluid is named *liquor sanguinis;* the particles are the *blood- and lymph-corpuscles*, or *cells.*

When blood flows from the living body, it is a thickish heavy fluid, of bright scarlet color when it comes from an artery; deep purple, Modena, or nearly black, when it flows from a vein. Its specific gravity at 60° F. is, on an average, 1055, that of water being reckoned as 1000; and the extremes consistent with health being, according to Nasse, 1050 and 1059 (xv. vol. i. p. 82). Its temperature is, generally, 100° F.; it has a slight alkaline reaction; and emits an odor similar to that which issues from the skin or breath of the animal from which it flows, but fainter.

The above-mentioned *differences of color* in arterial and venous

blood are sometimes not to be observed. If blood runs very slowly from an artery, as from the bottom of a deep and devious wound, it is generally as dark as venous blood. In climates of high temperature also, the arterial blood is dark and hardly to be distinguished from venous blood. (John Davy, lxxxv. vol. ii. p. 140.) In persons nearly asphyxiated, also, and sometimes under the influence of chloroform or ether, the arterial blood becomes like the venous. But in all these cases the dark blood becomes bright on exposure to the air.

The *specific gravity* of men's blood is, on an average, rather greater than that of women's, because of the larger proportion of red-corpuscles in the former; that of robust persons, for the same reason, is greater than that of the feeble. It is always diminished by bleeding; and so quickly that, in a single venesection, the specific gravity of a portion of the blood last drawn is often less than that of the blood that flows first. (J. Davy, lxxxv. vol. ii. p. 28: Polli, xci.) The specific gravity of blood is increased in diseases attended with great watery discharges, as cholera and diabetes; but with these exceptions, a specific gravity above the natural standard would generally indicate a disease attended with plethora, or excess of the animal constituents of blood, and a low specific gravity, a disease of debility or exhaustion.

The *alkaline reaction* is said to be a constant character of blood in all animals and under all circumstances. An exception has been supposed to exist in the case of menstrual blood; but the acid reaction which this sometimes presents is due to the mixture of an acid mucus from the uterus and vagina. Pure menstrual blood, such as may be obtained with a speculum, or from the uteri of women who die during menstruation, is always alkaline, and resembles ordinary blood. (Whitehead, lxxxvi.)

The *odor*, of blood is easily perceived in the watery vapor, or *halitus*, as it is called, which rises from blood just drawn: it may also be set free, long afterwards, by adding to the blood a mixture of equal parts of sulphuric acid and water. It is not difficult to tell, by the likeness of the odor to that of the body, the species of domestic animal from which any specimen of blood has been taken: the strong odor of the pig or cat, and the peculiar milky smell of the cow, are especially easy to be thus discerned in their blood. (Barruel, lxxxvii. No. 1.)

Coagulation of the Blood.

When blood is drawn from the body, and left at rest, certain changes ensue which constitute a kind of rough analysis of it, and are instructive respecting *the nature* of some of its constituents. *After about ten minutes, taking a general* average of many observations, *it gradually clots or congulates,* becoming solid, like a soft

jelly. The clot thus formed has at first the same volume and appearance as the fluid blood had, and, like it, looks quite uniform: the only change seems to be that the blood which was fluid is now solid. But presently, drops of transparent yellowish fluid begin to ooze from the surface of the solid clot; and these gradually collecting, first on its upper surface, and then all around it, the clot, diminished in size, but firmer than it was before, floats in a quantity of yellowish fluid which is named *serum*, and the quantity of which may continually increase for from twenty-four to forty-eight hours after the clotting of the blood. (Figs. 10 and 11.)

Fig. 10.

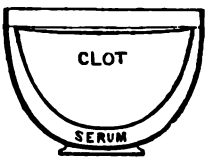
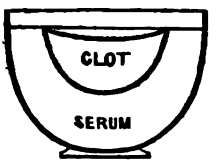


Fig. 11.



The changes just described may be thus explained. The *liquor sanguinis*, or liquid part of the blood, consists of serum, holding fibrine in solution. The peculiar property of fibrine, as already said (p. 15), is its tendency to become solid when at rest, and in some other conditions. When, then, a quantity of blood is drawn from the vessels, the fibrine being (in the normal state) equally diffused through the whole mass, coagulates, and serum and blood-corpuscles are held, or, as it were, soaked and entangled in the solid substance which it forms.

But after healthy fibrine has thus coagulated, it always contracts; and what is generally described as one process of coagulation should rather be regarded as consisting of two parts or stages; namely, first, the simple act of clotting, coagulating, or becoming solid; and, secondly, the contraction or condensing of the solid clot thus formed. By this second act, much of the serum which was soaked in the clot is gradually pressed out; and this collects in the vessel round the contracted clot.

Thus, by the observation of blood within the vessels, and of the changes which commonly ensue when it is drawn from them, we may distinguish it in three principal constituents, namely, 1st, the fibrine, or coagulating substance, which has been also called the lymph, or coagulating lymph of the blood; 2, the serum, in which the fibrine, before its coagulation, was dissolved; 3, the blood- and lymph-corpuscles.

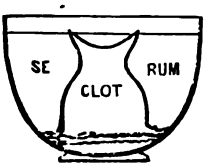
That the fibrine is the only spontaneously coagulable material in the blood, may be proved in many ways; and, most simply, by

y which a portion of the liquor sanguinis, *i. e.*, the brine, can be separated from the red corpuscles before

This separation is always effected when coagulation beyond the usual time, or when the red corpuscles, a higher specific gravity than the other constituents of sink more rapidly than usual. Coagulation may be cold, or by drawing the blood into a vessel containing as the oil floats over it, it may be excluded from the red corpuscles, also, sink quickly in blood drawn from th inflammatory diseases, and in horses' blood. In any es the red corpuscles may be observed, while the blood is o sink below its surface; and the layer beneath which sunk, and which has usually an opaline or grayish white oagulate without them, and form a white clot consisting of ie, or of fibrine with entangled white corpuscles; for the puscles being very light, tend upwards towards the sur- ie fluid. The layer of white clot which is thus formed ie top of a colored clot of ordinary characters, *i. e.*, of ich the coagulating fibrine has entangled the red corpus- they were sinking; and, thus placed, it constitutes what alled a *buffy coat.*

so by the action of the fibrine t the contraction of the clot is nd the contraction is greatest least hindered by particles in- the solid fibrine. Hence, when at is formed in the manner just , it commonly contracts more rest of the clot does, and, draw- its sides, produces that *cupped* e on the top of the clot which haracteristic of the existence of inflammation. (Fig. 12.) us evident that the coagulation of the blood is due to its We are not able to explain certainly why fibrine coagu- t the most reasonable hypothesis is, that its coagulation s of organization—a spontaneous assumption of organic structures which, in favorable conditions, would be the towards the formation of a more highly organized tissue. ipal evidence for this view is as follows :—

Fig. 12.



en the coagulation of fibrine is observed with the micro- d this may be easily done in a minute portion of liquor , taken when the red corpuscles are subsiding), it appears, ; solidified, soft, and quite homogeneous; but gradually, ecomes tougher, it acquires the appearance of a closely felt-like mass of fine white pliant fibrils, in which scat- ules and white corpuscles are imbedded. Such a fila-

mentous structure, with filaments separable by minute dissection, is observable in all well-formed fibrine clots, and is characteristic of organization; at least, such structures are not seen in inorganic matter, or in organic matter artificially coagulated, as albumen; but they are found in the more lowly organised tissues, such as that of the membrane of egg-shell (Carpenter, xciii. 1844, page 1), organising lymph, some of the least developed tumors, &c. (Fig. 13.)

Fig. 13.

Fibrous membrane lining the egg-shell, and forming the animal basis of the shell itself.

2. The coagulation of fibrine is hardly, if at all, distinguishable from that of lymph effused in inflammation. Both alike spontaneously coagulate in the same mode, and acquire the same simple structure; both alike contract after coagulation; and generally, when lymph effused in any case of inflammation has little tendency to organization, the fibrine of the patient's blood coagulates very weakly and imperfectly. It is on the whole probable that the lymph of inflammatory effusion is the fibrine of the blood only somewhat modified by the disease. But the lymph, after coagulating, goes on to more perfect organization, and becomes a vascular tissue; the fibrine shows no such further change, at least in blood drawn from the body. Yet, seeing that the coagulation of the lymph is the first step in its organization, it appears reasonable to regard the similar change in the fibrine as also organization, and to explain the subsequent difference between them by the difference of their external conditions. The lymph continues to be organized, being placed among living organizing parts that may supply it with the necessary materials for its support; the fibrine does not so continue, having none of these, perhaps essential, advantages.

3. The coagulation of blood out of the body is not different from its coagulation, under certain conditions, within the body, as *e. g.*, when the circulation through a vessel is obstructed by a ligature, or when blood is effused from its vessels into an adjacent cavity or tissue. And there is sufficient evidence that, in many cases, when the blood thus coagulates in contact with healthy living tissues, its coagulation is the first step towards a more complete organization, and the formation of vascular tissue; just as the coagulation of the lymph effused in inflammation is the beginning of its complete organization. The instances in which this organization of blood, or rather of the fibrine of blood, has been best observed, are those in which the blood coagulates above a ligature on

forms there what is called the *conical clot.* Such
ly loses its color by the disintegration of the red
y the absorption of its serum it becomes firmer and
acquires the structure of fine filamentous tissue, and
oodvessels; it is more and more intimately united
s of the vessel, and at length forms part of the
y which, finally, the obliterated portion of the artery
In this process, which has been minutely examined
xxix.), the changes through which the fibrine of the
ıre, in all essential respects, similar to those which
ı organization of lymph into false membrane or adhe-
tless the process is similar by which effused blood is,
er cases, organized; as, for example, in apoplexy of
aembranes, in which a thin layer of blood having coagu-
traced through stages of organization till it is nearly
ıto a tough membrane lining the dura mater; or in
the effusion of blood is more abundant, a layer on
f the clot may form a sac or cyst of finer membrane,
transparent like the arachnoid, and inclosing the rest
l (see especially Dr. Burrows, lxxi. 1835; and Mr.
xli. 1845). Such organization of clots of blood is also
in tumors attached to the interior of the heart, and
of the arteries, as well as in the formation of phlebo-
in-stones, and of the cords by which veins after slight
in phlegmasia dolens, are often obstructed or oblite-

ıe principal evidence for ascribing the coagulation of
organization of the fibrine. It is true that blood, when
in the living body, does not always proceed to further
; but this may be ascribed to the failure or absence of
itions favorable or perhaps essential to the process. Of
ons the principal are, 1st, that the blood should be free
nges induced by certain diseases, as typhus, bronchitis,
fections attended with dyspnœa; 2d, that it should be
all, exposed to the air; 3d, that, when it coagulates,
in contact with healthy, or nearly healthy parts; and
clot should be not so large but that it may all be near
arts. It is probably for want of the third condition
s in aneurismal sacs and in cerebral apoplectic effusions
ıer organized; the parts with which they lie in contact
/ able to maintain their own nutrition, or to repair the
y have themselves sustained. And, in very large effu-

eums contain such specimens. In the Museum of the Royal
rgeons, Nos. 12, 1528, 1732, 1733, 1742, may be referred to:
Bartholomew's Hospital, Nos. 1 and 3 in Series vi., 107 in
and 49 in Series xiv.

sions, the distance of the central part of the clot from the living tissues seems too great to admit of its further organization; just as, in morbid growths, the central parts are apt to degenerate through the insufficiency of the supply of materials for their nutrition.

It may be added, that arterial blood is, on the whole, more likely to be completely organized than venous blood is. Effused venous blood often remains for many days or weeks without coagulating; arterial blood very rarely does so; (Garengeot, xcii. tome ii.;) and clots of venous blood, when partially organized, are very liable to deposits of calcareous matter; a form of degeneration which is seldom or never observed in organized clots of arterial blood.

The evidence that coagulation of blood is due to the organization of its fibrine, justifies Mr. Hunter's expression, that "coagulation is an operation of life," (I. vol. iii. n. 34;) for here he used the term "life" in the same sense as that in which one speaks of a live egg, or a live seed, implying not an active state of life, but the capacity of developing and acquiring higher organization in conditions favorable to life. And the fact that the coagulation of blood may be suspended for any length of time by freezing it, or by adding to it large quantities of alkaline salts, is no more a disproof of Mr. Hunter's doctrine than the fact that eggs are not developed except at a certain temperature is a proof that they are incapable of development. Nothing more is proved by such a fact, than that certain external conditions are necessary for the perfect performance of these as of all other "operations of life."

Conditions affecting Coagulation.

Although the coagulation of fibrine is, like other processes of organization, spontaneous, yet it is liable like them to be modified by the conditions in which it is placed, such as temperature, motion, the access of air, the substances with which it is in contact, the mode of death, &c. All these conditions need to be considered in the study of the coagulation of the blood.[1]

Cold retards the coagulation of blood, and it is said that, so long as blood is kept at a temperature below 40° F., it will not coagulate at all. Freezing the blood, of course, prevents its coagulation; yet it will coagulate, though not firmly, if thawed after being frozen; and it will do so even after it has been frozen for several months. Coagulation is accelerated, but the subsequent contraction of the clot is hindered, by a temperature between 100° and 120°: a higher temperature retards coagulation, or, by coagu-

[1] The fullest accounts of them all are given by Nasse (xv. vol. i. Art. *Blut.*), and Gulliver, in his edition of Hewson's Works for the Sydenham Society.

lating the albumen of the serum, prevents the coagulation of the fibrine.

Rest is favorable to the coagulation of blood. Blood of which the whole mass is kept in uniform motion, as when a closed vessel completely filled with it is constantly moved, coagulates very slowly and imperfectly. But rest is not essential to coagulation; for the coagulated fibrine may be quickly obtained from blood by stirring it with a bundle of small twigs; and whenever any rough points of earthy matter or foreign bodies are introduced into the blood-vessels, the blood soon coagulates upon them. Neither is rest sufficient for the coagulation of the blood when other conditions are unfavorable; for coagulation is very slow in the body after death, although the blood is motionless.

The *free access of air* is, perhaps, of all external conditions that which is most favorable to coagulation. It is supposed to be so, by favoring the exhalation of carbonic acid from the blood; for many experiments by Dr. Polli (xc. April, 1843), seem to show that the more freely carbonic acid can be evolved, the quicker is the coagulation of the blood; and that the larger the quantity of the same gas contained in the blood, the slower is its coagulation. The same conclusion is made probable by the blood coagulating very slowly when placed in carbonic acid, but as quickly as usual in hydrogen or nitrogen, into which carbonic acid may be evolved as freely as into atmospheric air. The conclusion, however, is not yet sure; for Dr. John Davy says that carbonic acid is not evolved from coagulating blood (lxxxv. vol. ii. p. 86).

Whatever be the explanation, many facts show that coagulation is accelerated by the free access of air, and retarded by the opposite condition. Thus, it is quick when blood is drawn slowly, and slow when it is drawn quickly; because in the former case the blood is more fully exposed to the atmosphere than in the latter. To this also we may refer it that coagulation is quicker in shallow than in tall and narrow vessels; because in the former a large surface of blood is exposed to the air; and to this (at least principally) that the blood in the dead body often remains fluid for from twelve to twenty-four hours after death, and then coagulates within a few minutes after it is let out of the vessels and exposed to the air. Yet, favorable as the access of air may be, we cannot regard the change that it produces as in any sense the cause of the coagulation of the blood; for coagulation will take place in a vacuum, and in the most remote parts of the body, into which we cannot suppose that free atmospheric air can make its way either during life or after death, as, for example, in the brain.

Lastly, the *multiplication of points of contact* seems a favorable condition for coagulation. Thus, when all other conditions are unfavorable, the blood will coagulate upon rough bodies projecting

into the vessels; as, for example, upon threads passed through arteries or aneurismal sacs, on the heart's valves roughened by inflammatory deposits, or calcareous accumulations. And, perhaps, this may explain the quicker coagulation of blood after death in the heart with walls made irregular by the fleshy columns, than in the simple smooth-walled arteries and veins.

It has been believed, and chiefly on the authority of Mr. Hunter, that, after certain modes of death, the blood does not coagulate: he enumerates the death by lightning, over-exertion (as in animals hunted to death), blows on the stomach, fits of anger. He says: "I have seen instances of them all." Doubtless, he had done so; but the results of such events are not constant. The blood has been often observed coagulated in the bodies of animals killed by lightning or an electric shock; and lately, Mr. Gulliver (lxxi. vol. xli. p. 1087) has published instances in which he found clots in the hearts of hares and stags hunted to death, and of cocks killed in fighting.

The Blood-Corpuscles, or Blood-Cells.

It has been already said that the clot of blood contains, with the fibrine and the portion of the serum that is soaked in it, the *blood-corpuscles* or *blood-cells*. Of these there are two principal forms, the red and the white corpuscles, of which the latter are in process of being developed into the former. When coagulation has taken place quickly, both kinds of corpuscles may be uniformly diffused through the clot; but, when it has been slow, the red corpuscles, being the heaviest constituent of the blood, tend by gravitation to accumulate at the bottom of the clot; and the white corpuscles, being among the lightest constituents, collect in the upper part, and contribute to the formation of the buffy coat.

The *human red blood-corpuscles* (Fig. 1) are circular flattened cells of different sizes, the majority varying in diameter from 1-3000th to 1-4000th of an inch, and about 1-10,000th of an inch in thickness.[1] Their borders are rounded; their surfaces, in their most perfect and usual state, slightly concave; but they readily acquire flat or convex surfaces when the liquor sanguinis being diluted they are swollen by absorbing more fluid into their cavity. They are composed of a delicate, and probably colorless, membranous cell-wall, which incloses a peculiar substance impregnated with the red coloring matter, or hæmatine. Their cell-walls are tough and elastic; so that, as they circulate, they admit of elongation and various changes of form in adaptation to the vessels, yet recover their natural shape as soon as they escape from compression.

[1] Mr. Gulliver has given, in his edition of Hewson's Works, p. 237, a table of the sizes of the red corpuscles in numerous species of vertebrate animals.

They have no nuclei, and their contents are probably homogeneous; at least they appear so, when their surfaces are flat or slightly convex; it is only when they are concave that the unequal refraction of transmitted light gives the appearance of a central spot, which is brighter or darker than the border, according as it is viewed in or out of focus.

In examining a number of red corpuscles with the microscope, it is easy to observe certain natural diversities among them, though they be all taken from the same part. The great majority, indeed, are very uniform; but some are larger than these, and the larger ones generally appear paler and less exactly circular than the rest; their surfaces also are, usually, flat or slightly convex; they often contain a minute shining particle like a nucleolus, and they are lighter than the rest, floating higher in the fluid in which they are placed. These differences are connected with the development of the blood-corpuscles, and will be explained in the account of that process. Other deviations from the general characters assigned to the corpuscles depend on changes that occur after they are taken from the body. Very commonly they assume a granulated form, in consequence, apparently, of a peculiar corrugation of their cell-walls. The larger cells are much less liable to this change than the smaller ones are, and the natural shape may be restored by diluting the fluid in which the corpuscles float; by such dilution the corpuscles, as already said, may be made to swell up by absorbing the fluid; and, if much water be added, they will become spherical and pellucid, their coloring matter being dissolved, and, as it were, washed out of them. Some of them may thus be burst; the others are made obscure; but many of these may be brought into view again by evaporating, or adding saline matter to, the fluid, so as to restore it to its previous density. The changes thus produced by water are more quickly effected by weak acetic acid, which immediately makes the corpuscles pellucid, but dissolves few or none of them, for the addition of an alkali so as to neutralize the acid will restore their form, though not their color.[1]

A peculiar condition of the red corpuscles in inflammatory blood—a condition which appears to exist naturally in the blood of horses—is the principal cause of the formation of the buffy coat. It gives them a great tendency to adhere together in rolls or columns, like piles of coins, and then, very quickly, these rolls fasten together by their ends, and cluster; so that, when the blood is spread out thinly on a glass, they form a kind of irregular network, with crowds of corpuscles at the several points corresponding with the

[1] On the effects of various reagents on the blood see Gulliver (xxviii.), Nasse (xv. art. *Blut.*); and on those produced by gases see Harless (ciii.).

knots of the net.[1] Hence, the clot formed in such a thin layer of blood looks mottled with blotches of pink upon a white ground: in a larger quantity of such blood, as soon as the corpuscles have clustered and collected in rolls (that is, generally in two or three minutes after the blood is drawn), they begin to sink very quickly; for in the aggregate they present less surface to the resistance of the liquor sanguinis than they would if sinking separately. Thus quickly sinking, they leave above them a layer of liquor sanguinis, and this coagulating forms a buffy coat, the volume of which is augmented by the white corpuscles, which have no tendency to adhere to the red ones, and by their lightness float up clear of them.

The *white corpuscles* are much less numerous than the red ones. On an average, in health, there may be one white to fifty red corpuscles; but, in disease, the proportion is often as high as one to ten, and sometimes, even much greater (clxxxix. Jan. 1851, p. 17, and lxxi. 1851, p. 147). They present greater diversities of form than the red ones do; but the gradations between the extreme forms are so regular that no sufficient reason can be found for supposing there is, in healthy blood, more than one species of white corpuscles. In their most general appearance they are circular and nearly spherical, about 1-2500th of an inch in diameter, tuberculated on their surfaces (Fig. 14), 1. They have a grayish, pearly look, appearing variously shaded or nebulous, the shading being much darker in some than in others. They seem to be formed of some white substance, variously refracting the light, and containing granules which are in some specimens few and very distinct, in others (though rarely) so numerous that the whole corpuscle looks like a mass of granules.

Fig. 14.

White corpuscles of the blood. 1. A corpuscle in its natural condition. 2 and 3. Different appearances produced by the action of diluted acetic acid.

In a few instances, a distinct cell-membrane can be at once traced round a corpuscle thus composed; but, much more commonly, none can be demonstrated, till water or diluted acetic acid being added penetrates the corpuscle, and lifts up and distends a cell-wall, to the interior of which the material, that before appeared to form the whole corpuscle, remains attached as the nucleus of the cell. Thus these corpuscles are demonstrated to be nucleated cells, the nuclei of which are soft, granular, or tuberculated masses, and fill the cavities of the cells. The diversities presented by the nuclei,

[1] The appearance is represented by Mr. Wharton Jones (xciv. vol. lx. p. 311), who first very accurately described it. See also, for some interesting facts connected with it, Gulliver, in his edition of Hewson's Works.

which, by the action of water, are sometimes scarcely changed, sometimes broken into two or three pieces (Fig. 14) 3, and sometimes completely disintegrated and diffused through the cell, appear to be connected with the development of the corpuscles, and will be again referred to. So will the relation between the white and the red corpuscles. (See page 65.)

The Serum.

The *serum* is the liquid part of the blood remaining after the coagulation of the fibrine. In the usual mode of coagulation, part of the serum remains soaked in the clot, and the rest, squeezed from the clot by its contraction, lies around and over it. The quantity of serum that appears around the clot depends partly on the total quantity in the blood, but partly also on the degree to which the clot contracts. This is affected by many circumstances: generally, the faster the coagulation, the less is the amount of contraction; and, therefore, when blood coagulates quickly, it will appear to contain a small proportion of serum. Hence, the serum always appears deficient in blood drawn slowly into a shallow vessel, abundant in inflammatory blood drawn into a tall vessel. In all cases, too, it should be remembered, that, since the contraction of the clot may continue for thirty-six or more hours, the quantity of serum in the blood cannot be even roughly estimated till this period has elapsed.

The serum is an alkaline, slimy or viscid, yellowish fluid, often presenting a slight greenish or grayish hue, and with a specific gravity of from 1025 to 1030. It is composed of a mixture of various substances dissolved in about nine times their weight of water. It contains, indeed, the greater part of all the substances enumerated as existing in the blood, with the exceptions of the fibrine, globuline, and hæmatine. Its principal constituent is albumen, of which it contains about 8 per cent. and the coagulation of which, when heated, converts nearly the whole of the serum into a solid mass. The liquid which remains uncoagulated, and which is often inclosed in little cavities in the coagulated serum, is called *serosity:* it contains, dissolved in water, fatty, extractive, and saline matters, and a compound somewhat resembling albumen, but not coagulable, which Mulder considers to be a tritoxide of proteine (lxi.).[1]

Chemical Composition of the Blood.

Among the many analyses of the blood that have been published, some, in which all the constituents are enumerated, are inaccurate

[1] See the translation of parts of this work in the London Medical Gazette, Feb., Sept., and Oct., 1844.

in their statements of the proportions of those constituents; others, admirably accurate in some particulars, are incomplete.[1] The two following tables, constructed chiefly from the analyses of Denis, Lecanu, Simon, Nasse, Lehmann, Becquerel, Rodier, and Gavarret, are designed to combine, as far as possible, the advantage of accuracy in numbers with the convenience of presenting at one view a list of all the constituents of the blood.

Average proportions of the principal constituents of the blood in 1000 parts:—

Water	784.
Red corpuscles	131.
Albumen of serum	70.
Saline matters	6.03
Extractive, fatty, and other matters	6.77
Fibrine	2.2
	1000.

Average proportions of all the constituents of the blood in 1000 parts:—

Water			784.
Albumen			70.
Fibrine			2.2
Red Corpuscles:	Globuline		123.5
	Hæmatine		7.5
Fatty matters:	Cholestearine	0.08	1.3
	Cerebrine	0.4	
	Seroline	0.02	
	Oleic and margaric acids		
	Volatile and odorous fatty acid		
	Fat containing phosphorus		
Inorganic salts:	Chloride of sodium		3.6
	Chloride of potassium		0.36
	Tribasic phosphate of soda		0.2
	Carbonate of soda		0.84
	Sulphate of soda		0.28
	Phosphates of lime and magnesia		0.25
	Oxide and phosphate of iron		0.5
Extractive matter, with salivary matter, urea, biliary coloring matter, gases, and accidental substances			5.47
			1000.

Elementary composition of the dried blood of the ox:—

Carbon	57.9 per cent.
Hydrogen	7.1
Nitrogen	17.4
Oxygen	19.2
Ashes	4.4

[1] An exception may be made in favor of the complete analysis of the blood of man and several animals, lately published by Poggiale (xviii. t.xxv. p. 110).

These results of the ultimate analysis of ox's blood afford a remarkable illustration of its general purpose as supplying the materials for the renovation of all the tissues. For the same analysts (Playfair and Boeckmann) have found that the flesh of the ox yields the same elements in so nearly the same proportions, that the elementary composition of the organic constituents of the blood and flesh may be considered identical, and may be represented for both by the formula $C_{45}H_{39}N_6O_{15}$.

After what has been said of many of the constituents of the blood, in the chapter on the CHEMICAL COMPOSITION OF THE BODY, a few words on each of the principal of them may here suffice.

The *water of the blood* is subject to hourly variations in its quantity, according to the period since the taking of food, the amount of bodily exercise, the state of the atmosphere, and all the other events that may affect either the ingestion or the excretion of fluids. According to these conditions, it may vary from 700 to 790 parts in the thousand. Yet uniformity is on the whole maintained; because nearly all those things which tend to lower the proportion of water in the blood, such as active exercise, or the addition of saline and other solid matter, excite thirst; while, on the other hand, the addition of an excess of water to the blood is quickly followed by its more copious excretion in sweat and urine. And these means for adjusting the proportion of the water find their purpose in maintaining certain important physical conditions in the blood; such as its proper viscidity, and the degree of its adhesion to the vessels, through which it ought to flow with the least possible resistance from friction. On this also depends, in great measure, the activity of absorption by the bloodvessels, into which no fluids will quickly penetrate, but such as are of less density than the blood. Again, the quantity of water in the blood determines, chiefly, its volume, and thereby the fulness and tension of the vessels, and the quantity of fluid that will exude from them to keep the tissues moist. Finally, the water is the general solvent of all the other materials of the liquor sanguinis, and its abundance greatly favors organic chemical action: for generally, and within limits of health, the amount of action in the organic life of the several parts of the body is in direct proportion to the quantity of water they severally contain. Compare, *e. g.*, in these respects, the bones or tendons with the muscles; or any tissue with the blood; or any of the tissues of young animals with the same in old ones: in all such cases, abundant water appears connected with activity of organic life.

It is remarkable that the proportion of water in the blood may be sometimes increased even during its abstraction from an artery or vein. Thus Dr. Zimmerman (ix. vol. iv. p. 385), in bleeding dogs, found the last drawn portion of blood contain 12 or 13 parts

more of water in 1000 than the blood first drawn; and Polli (xii.) notices a corresponding diminution in the specific gravity of human blood during venesection, and has suggested the only probable explanation of the fact, namely, that during bleeding, the bloodvessels absorb very quickly a part of the serous fluid with which all the tissues are moistened.

The *albumen* may vary, consistently with health, from 60 to 70 parts in the 1000 of blood. The form in which it exists in the blood is not yet certain. It may be that of simple solution as pure albumen: but it is, more probably, in combination with soda, as an albuminate of soda; for, if serum be much diluted with water, and then neutralised with acetic acid, pure albumen is deposited. Another view, entertained by Enderlin (x. March and April, 1844), is that the albumen is dissolved in the solution of the tribasic phosphate of soda, to which he considers the alkaline reaction of the blood to be due, and solutions of which can dissolve large quantities of albumen and phosphate of lime.

Fibrine.—The proportion of fibrine in healthy blood may vary between 2 and 3 parts in 1000. In some diseases, such as typhus, and others of low type, it may be as little as 1.034; in other diseases, it is said, it may be increased to as much as 7.528 parts in 1000. But, in estimating the quantity of fibrine, chemists have not taken account of the white corpuscles of the blood. These cannot, by any mode of analysis yet invented, be separated from the fibrine of mammalian blood: their composition is unknown, but their weight is always included in the estimate of the fibrine. In health, they may, perhaps, add too little to its weight to merit consideration: but in many diseases, especially in inflammatory and other blood-diseases in which the fibrine is said to be increased, these corpuscles become so numerous that a large proportion of the supposed increase of the fibrine must be due to their being weighed with it. On this account all the statements respecting the increase of fibrine in certain diseases need revision.

The quantity of fibrine appears to be, generally rather greater in arterial than in venous blood; and to be less in the blood of the splenic and portal veins than in ordinary venous blood. According to Denis, the fibrine of venous blood differs from that of arterial in that, when it is fresh and has not been much exposed to the air, it may be dissolved in a slightly heated solution of nitrate of potash. Mulder considers that the apparent peculiarity of the fibrine of arterial blood is due to the mixture of oxides of proteine, formed as often as the blood traverses the lungs: and that these, also, constitute part of the buffy coat and apparent increase of fibrine in inflammatory diseases.

Globuline, and *Hæmatine*, or *Hæmatosine*, mixed in a compound, which has been named *Hæmato-globulin*, or *Cruor*, constitute the

substance contained in the red blood-corpuscles. The cell-walls of these minute bodies cannot, indeed, be completely separated from their contents, or chemically distinguished from the globuline: and hence, perhaps, the diversity in the statements respecting the proportions of globuline and hæmatine. Berzelius states the proportion of hæmatine at 5.8 per cent. of the compound; Schmidt (x. No. lxi. p. 165) at 12.41 per cent. having, perhaps, more completely separated the walls from the contents of the blood-corpuscles.

Globuline appears to be a proteine-compound. According to Simon (lxxxii. vol. i. p. 81) it bears most resemblance to caseine, on which account he named it caseine of blood; but Liebig and others regard it as more similar to albumen. It is soluble in water, and its solution, when heated, forms a granular coagulum. Its composition, according to Mulder, is,

Carbon	54.11
Hydrogen	7.17
Nitrogen	15.7
Oxygen	20.52
Sulphur	2.5

But the chemical nature of globuline cannot be exactly determined, because it cannot be obtained quite pure from either hæmatine or the membranous walls of the blood-cells, the mixture of which, as Henle suggests (xxxvii. p. 55), is probably sufficient to explain its apparent differences from common albumen.

Hæmatosine, or *Hæmatine*, is distinguished from all other animal matter by its peculiar blood-color, and by the changes which this color presents when, being incorporated in the blood-corpuscles, it is exposed to oxygen, carbonic acid, and other gases. It is soluble in water, by which, as already said, it may, with the globuline, be washed out of the blood-corpuscles: and from this solution it is precipitated by most metallic salts, and by concentrated acids. In the living, or recent, state of the blood-corpuscles, the hæmatine is confined within their cell-walls, and appears to be insoluble in the serum; but when the blood begins to decompose, and the cell-walls, losing their texture, permit the outward passage of their contents, both the hæmatine and the globuline are dissolved in the serum, which thus becomes blood-colored, and may impart its tinge to the surrounding parts. With the globuline, also, hæmatine appears to be coagulated by heat; but, according to Mulder, it is only inclosed in the coagulum of the globuline, without being itself coagulable. In the purest state in which it can be obtained,[1] it is so far changed as to be insoluble in water, of a deep brackish-

[1] On the several modes of obtaining it, see Simon (lxxxii.), Fownes (lx.), Griffiths (cii.), and Garrod (xxx. 1848, vol. i. p. 654).

brown color, and not liable to change of color on exposure to gases. Boiling alcohol will dissolve small quantities of it, and it is freely soluble in alcohol acidulated with sulphuric, hydrochloric, or nitric acid, and in weak solutions of potash, soda, or ammonia.

According to Mulder, pure hæmatine consists of

Carbon	65.84 per cent.
Hydrogen	5.87
Nitrogen	10.4
Oxygen	11.75
Iron	6.64

and he assigns for its formula $C_{44}H_{28}N_3O_6Fe$.

The presence of so large a proportion of iron constitutes a peculiar feature in hæmatine. The mode in which the metal exists in it has been much discussed. By some it is supposed to be in the form of an oxide, or a salt, or in the form of peroxide in arterial blood, and carbonate of the protoxide of iron in venous blood. (Liebig, xi.) But the greater probability is, that the iron is combined as an element with the four essential elements, in the same manner as, it is held, sulphur is combined with them in albumen, fibrine, cystic oxide, &c. The principal evidence for this view, which is especially supported by Scherer and Mulder, is, 1, that when chlorine, which would not decompose an oxide of iron, is passed through a solution of hæmatine, chloride of iron is formed, and the iron thus removed from the other elements of the hæmatine, is replaced by chlorous acid; 2, that all the iron may be removed from hæmatine by sulphuric acid, without abstracting from it any of its oxygen, which would not be possible if the iron were more intimately united with the oxygen than with the other elements of the hæmatine; 3, that pure hæmatine may be exposed for several days to the action of dilute hydrochloric or sulphuric acid, without any loss of its iron; though these acids would dissolve an oxide of iron or decompose a carbonate.

The peculiar color of hæmatine depends less on the iron than on its other constituents, for, as Scherer and Mulder have shown, hæmatine may retain its color after all the iron is extracted from it. Therefore the changes of color produced by respiration, and the contact of gases with the blood, cannot be referred to any change in the state of the iron in the hæmatine. It is, indeed, very doubtful whether the rapid change of color which is effected in respiration, and on the contact of various gases, can be referred to any chemical changes whatever in the hæmatine; much more probably, it is due to changes in the form of the blood-corpuscles and their consequently different modes of reflecting and transmitting light. For, 1, the changes of color produced by carbonic acid and oxygen, mixed with a solution of the coloring matter of the blood, are very

t; they are generally scarcely perceptible, and when they are they are slowly produced, or are not more than may be ex- ed by the action of the gases on some corpuscles still suspend- i the solution ; 2, the same changes of color as are produced rbonic acid and oxygen acting on the corpuscles, may be pro- d by distilled water, and strong solutions of alkaline salts. A k clot of blood becomes at once scarlet by washing it with salt, is not blackened again by carbonic acid ; a scarlet one is made k by washing it with distilled water, and is only very slowly lened again by the contact of oxygen. Now the changes thus luced by salt and by water acting on the corpuscles, are not luced by the addition of the same substances to a solution of satine, and are not connected with any chemical change in ; substance or in the corpuscles ; but they are connected with rations in the shape of the red corpuscles, for saline solutions, lenser than the liquor sanguinis, contract and shrivel up the puscles, making them deeply bi-concave; and distilled water has contrary effect, swelling out the corpuscles and making them kly bi-convex or spherical. Changes corresponding with these produced by the contact of oxygen and of carbonic acid with corpuscles: the former contracting them, and making their cell- mbranes thick and granular; the latter dilating them, and thin- g, and finally dissolving their cell-walls; and effecting these nges in a degree which, however slight it may appear in a gle corpuscle, is enough to account for the change of color in a s of blood. Herein, then, is a sufficient explanation of the nges that the corpuscles undergo, without supposing any im- diate chemical alteration in the hæmatine ; an alteration which uld take place as well in a solution of hæmatine as in the cor- cles.

The opinion that the instantaneous change of color which takes ce in blood exposed to the action of oxygen or carbonic acid is to a physical rather than a chemical alteration in the corpus- s, is quite consistent with the probability that the corpuscles are mically changed by the longer action of those gases dissolved the blood. It appears that entire blood will absorb much more gen than either serum or liquor sanguinis alone will ; as if it e chiefly with the corpuscles that the absorbed oxygen combines. his be true, we may conclude, from the whole, that the oxygen, first contracting the corpuscles and thickening their walls, makes m so reflect light as to appear, in mass, bright-red, and then mically combines with them ; and that carbonic acid, by dilat- them and thinning their walls, makes them reflect less light, appear, in mass, nearly black ; but we have no means of de- mining how large a portion of the oxygen inspired combines

with the corpuscles, nor whether that portion combines with the hæmatine or the globuline, or equally with both.[1]

The enumeration of the *fatty matters* of the blood makes it probable that most of those which are found in the tissues or secretions exist also ready-formed in the blood; for it contains the cholestearine of the bile, the cerebrine and phosphorised fat of the brain, and the margaric and oleic acids of common fat. The fat named seroline appears to be peculiar to the blood. The volatile fatty acid is that on which the odor of the blood mainly depends; and it is supposed, that when the sulphuric acid is added (see p. 48,) it evolves the odor by combining with the base with which, naturally, this fat is neutralised.

The fatty matters of the blood are subject to much variation in quantity, being commonly increased after every meal in which fat, or starch, or saccharine substances have been taken. At such times, the fatty particles of the chyle, added quickly to the blood, are only gradually assimilated; and their quantity may be sufficient to make the serum of the blood opaque, or even milk-like.[2]

Of the *inorganic constituents* of the blood—the substances which remain as *ashes* after its complete burning—one may observe in general their small quantity in proportion to that of animal matter contained in it. Those among them of peculiar interest are the phosphate and carbonate of soda, and the phosphate of lime.

It appears most probable that the blood owes its alkaline reaction to both these salts of soda. The existence of the tribasic phosphate, a salt consisting of one equivalent of phosphoric acid with two of soda and one of basic water ($PO_5+2Na\,O+HO$), was proved by Enderlin (x. 1844). His experiments showed that the alkaline reaction of the blood, and of solutions of its ashes, could not depend, as some had supposed, on free soda; and seemed to prove, also, that the blood could not contain an alkaline carbonate. He, therefore, concluded that the alkaline reaction of the blood is wholly due to the tribasic phosphate of soda, and Liebig has supported this view by showing that it is impossible to evolve any carbonic acid by adding hydrochloric acid to a very concentrated solution of the alkaline salts of the blood. But Marchand (cxxiv. vol. xxxvii. p. 321), Lehmann (lix. 1847, p. 88), and others, explain this by the fact that the carbonic acid being evolved in a solution so capable of absorbing that gas as one of the tribasic phosphate of soda would be at once dissolved therein, and would not appear as gas

[1] The treatises on this subject are discussed by Scherer in his several reports in Canstatt's Jahresberichte since 1844. The chief original works are those of Scherer, Bruch, and Reuter, in Henle and Pfeufer's Zeitschrift from 1843 to 1847; Donders, Harless, Marchand, and Mulder.

[2] On the subject of milky serum, see Dr. R. D. Thomson (xxx. May, 1845), and Dr. Buchanan (lxxi. Oct. 1844).

escaping. A recent very careful series of analyses, by Lehmann, seem to have proved the existence of both the carbonate and the tribasic phosphate in the blood, and that they are, jointly, the source of its alkaline reaction. The quantities of the alkaline salts set down in the table at page 54 are adopted from his analysis.

In illustration of the characters which the blood may derive from the phosphate of soda, Liebig points out the large capacity which solutions of that salt have of absorbing carbonic acid gas, and then very readily giving it off again when agitated in atmospheric air, or when the atmospheric pressure is diminished. It is probably also by means of this salt that the phosphate of lime is held in solution in the blood in a form in which it is not soluble in water, or in a solution of albumen.[1]

Of the remaining constituents of the blood—the oxide and phosphate of iron referred to exist in the liquor sanguinis, independent of the iron in the corpuscles. What concerns the urea present in healthy blood, will be stated in speaking of the secretion of URINE: the existence of biliary coloring matter in it will be referred to in the section on BILE; and the gases it contains in the chapter on RESPIRATION.

Vital Properties and Actions of the Blood.[2]

The life of the blood is manifested, as already said, in its coagulation, and the subsequent more perfect organization which it may attain when it coagulates among healthy living tissues. But, in a higher degree, its life is shown in its development and self-maintenance, in its liability to idiopathic disease and death, and in the purpose and relation which connect it with the other living parts.

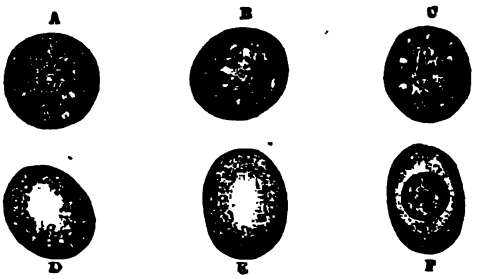
In the *development* of the blood, little more can be traced than the processes by which the corpuscles and fibrine are formed. In all the Vertebrata, two sets of red corpuscles are developed at different periods of life: a first set, which exist alone in the blood, till lymph and chyle begin to be formed; and a second set, which are formed from the lymph- and chyle-corpuscles, and gradually supersede the first set. The corpuscles of the first set are, in the first instance, part of the embryo-cells which form the mucous or vegetative layer of the embryos in Mammalia and birds, and the whole inner sur-

[1] The student will do well to refer to the interesting observations of Liebig, in his Chemistry of Food, respecting the mode in which the phosphate of soda is formed for the blood of herbivorous animals who take, in their food, phosphate of potash and chloride of sodium: and respecting the mutual action of the alkaline phosphate in the blood and the acid phosphate in the juice of the muscles.

[2] The following portion of this chapter contains an abstract of part of the Lectures on the Life of the Blood, delivered by Mr. Paget, at the College of Surgeons, in May, 1848.

face of the vitelline membrane, in the embryos of fish and reptiles. In the latter class, certain of these cells are laid out in the plan of the future heart and chief bloodvessels, before the walls of those organs are yet formed, and before the blood has begun to move. As described by Vogt (cv.), Kölliker (xxxi. 1846), and Cramer (lxxx. 1848, p. 631), they are large, colorless, vesicular, spherical cells, full of yellowish particles of a substance like fatty matter (Fig. 15, A); many of which particles are quadrangular and flatten-

Fig. 15.



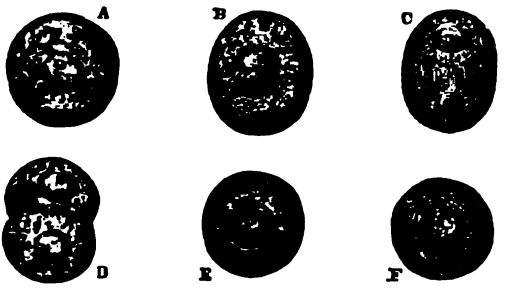
Development of the first set of blood-corpuscles in the Batrachian larva. A. An embryo-cell filled with fatty-looking particles. B, C, D, and E. Successive stages in the transition of the embryo-cell to a blood-corpuscle, as described in the text. F. A fully-formed blood-corpuscle.

ed, and have been called stearine-plates, though they are not proved to consist of that or any other unmixed fatty substance. Among these particles each cell has a central nucleus, which, however, is at first much obscured by them. The development of these embryo-cells into the complete form of the corpuscles is effected by the gradual clearing up, as if by division and liquefaction, of the contained particles, the acquirement of blood-color, and of the elliptical form, the flattening of the cell, and the more prominent appearance of the nucleus. The changes are so slowly accomplished in the tadpole of the frog, and in other batrachian embryos, that they may be easily traced in the blood while it flows in their transparent parts; a similar process appears to occur in the development of the blood-corpuscles of fish (Vogt, civ.), and there is little doubt that a similar one obtains in birds, though, since it is completed in the first forty hours of incubation, it is very difficult to trace it in all its successive stages. We have, however, seen in the heart of the chick, after from thirty to forty hours' incubation, some colorless spherical cells, with fatty-looking particles and granules, exactly similar to those of the mucous layer of the germinal area of the ovum. With these were others, which appeared to be of the same origin, but to have undergone

ges similar to those above described; a clearing up of the fatty cles, acquirement of color, reduction of size, and more distinct arance of the nucleus. The assumption of the flattened elliptiorm occurs in birds at a later period.

mammalian embryos, also, the earliest blood-corpuscles apto be a portion of the cells of the vegetative or mucous layer e germinal area. They are large, spherical or oval, pellucid colorless, nucleated, and full of minute granules (Fig. 16, A). hese we have observed (as Kölliker (xxxiii. 1846), Fahrner,) and others have done), a process of multiplication by bi-parn of the nucleus, each half of which, either by appropriating the cell, or by developing a cell around itself, becomes the ral nucleus of a new cell differing from the parent-cell from h it escapes, in little except in being smaller and more gener circular (B, C, and D). The subsequent changes of these resemble those already described; they gradually acquire the d-color, their granules disappear, and their surfaces become other and more uniform (E and F).

Fig. 16.



velopment of the first set of blood-corpuscles in the mammalian embryo. A. A dotted, nated embryo-cell in process of conversion into a blood-corpuscle: the nucleus provided a nucleolus. B. A similar cell with a dividing nucleus; at C, the division of the us is complete; at D, the cell also is dividing. E. A blood-corpuscle almost complete, ill containing a few granules. F. Perfect blood-corpuscle.

t seems, moreover, that in the mammalian corpuscles, these ages may ensue as well during, as after, the multiplication by tition of the nucleus: for red corpuscles are not unfrequent in nmalian embryos containing two nuclei, and we have seen some h three, and even four, nuclei.

he development of the first set of blood-corpuscles appears, s, to be uniform in all the classes of Vertebrata; namely, in all, a the embryo-cells of the vitelline membrane or germinal area, nucleated red blood-cells; the principal visible changes being

the disappearance of granules or fatty-looking substance, the greater prominence of the nucleus, and the acquirement of color. And, in their most perfect state, the corpuscles of the first set are in all the vertebrate classes nucleated cells. Those of the human embryo are circular, thickly disk-shaped, full-colored, and, on an average, about 1-2500th of an inch in diameter; their nuclei, which are about 1-5000th of an inch in diameter, are central, circular, very little prominent on the surfaces of the cell, and apparently slightly granular or tuberculated. In a few instances, cells are found with two nuclei; and such cells are usually large and elliptical, with one of the nuclei near each end of their long axis.

When, in the development of the embryo, the lymph and chyle begin to be formed and added to the blood, their corpuscles are developed so as to supersede those produced in the manner just described. In some species (as in the frog) the first appearance of lymph- and chyle-corpuscles in the blood exactly corresponds with the time at which the external branchiæ disappear; in others, as in the chick, rabbit, ferret, and sheep, their appearance coincides with the closure of the branchial fissures.[1] After they have once appeared the new blood-corpuscles appear to be derived exclusively through them. For some time, indeed, the two sets of corpuscles appear mingled in the blood. In this case, in Mammalia, the white corpuscles of the first set (if any remain in this stage) are distinguished from those of the second set, by their larger size, distinct cell-walls, small, well-defined central nuclei, and their pellucid contents with very minute scattered dots or granules; and the red corpuscles of the first set are always characterized by their larger size and their nuclei, which, if not at once distinct, are rendered so by the addition of water. But, gradually, while the corpuscles of the second set are increasing, those of the first disappear, and we believe they would not be found in a human embryo of more than two months old, unless in cases of arrested development; in such an one, where the abdominal walls were incomplete, we found the two sets of corpuscles mixed in the blood of a fœtus between three and four months old.

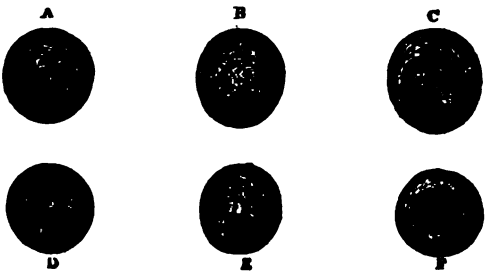
The origin and first formation of the lymph and chyle, and of their corpuscles, will be described in the chapter on ABSORPTION; the structure of the corpuscles (which are the white or colorless corpuscles of most writers, the granule-cells of Mr. Wharton Jones) is described already (p. 52). In the different vertebrate classes there is much greater similarity in these corpuscles than in the

[1] These instances prove a frequent coincidence in the development of the blood by the production of a new set of corpuscles through lymph and chyle, and of the respiratory apparatus by the suppression of the external branchial organs. But in the Triton punctatus we have found lymph-corpuscles in the blood while its long-retained external branchiæ still exist.

red blood-corpuscles of the second set. Except for some difference of size, the same general description might apply to all; and some features in the development are alike in all, namely, the gradual clearing up, as if by deliquescence, of their granular contents, and a commensurate acquirement of color. But, while in the corpuscles of the oviparous Vertebrata the outer part alone of their granular contents thus clears up, and the central part remains as the small nucleus of the complete blood-cell, in man, and all Mammalia, the whole of the contents clear up, acquire a uniform color, and become the homogeneous contents of a cell without a nucleus.

The principal steps in the development of the human lymph- or chyle-corpuscle into the red-corpuscle, may be traced in specimens of blood in which these white corpuscles are numerous. The white corpuscle, at first tuberculated, containing many granules, and darkly-shaded (Fig. 17, A), becomes smoother, paler, less granular, and more dimly shaded or nebulous (Fig. 17, B): changes corresponding with those which Mr. Wharton Jones describes as from the coarsely to the finely granular stage of the *granule-cell* (xliii. 1846). In these stages, the cell-wall may be easily raised from its contents by the contact and penetration of acetic acid, or by the longer action of water (Fig. 17, C); and, according to the stage of

Fig. 17.



Development of human lymph- and chyle-corpuscles into blood-corpuscles. A. A lymph or white blood-corpuscle. B. The same in process of conversion into a red corpuscle. C. A lymph-corpuscle with the cell-wall raised up round it by the action of water. D. A lymph-corpuscle from which the granules have almost all disappeared. E. A lymph-corpuscle acquiring color; a single granule, like a nucleus, remains. F. A red corpuscle fully developed.

development, so, as already stated, are the various appearances which the contents of the cell thus acted on present. In the regular progress of development, it becomes at length impossible to raise the cell-wall from its contents. Then the corpuscles acquire a pale tinge of blood-color; and this always coincides with the

softening of the shadows which before made them look nebulous, and with the final vanishing of all the granules, with the exception sometimes of one which remains some time longer like a shining particle in the corpuscle, and has probably been often mistaken for a nucleus (Fig. 17, E). The blood-color now deepens, and at the same rate the corpuscles become smooth and uniform; biconcave, having previously gradually changed the nearly spherical form for a lenticular or flattened one; smaller, apparently by condensation of their substance, for at the same time they become less amenable to the influence of water; more liable to corrugation and to collect in clusters; and heavier, so that the smallest and fullest-colored corpuscles always lie deepest in the field. Thus the most developed state of the mammalian red-corpuscles appears to be that in which it is full-colored, circular, biconcave, small, uniform, and heavy: this also is the state in which they appear to live the longer and most active portion of their lives.

This mode of development of new blood-corpuscles from those of the lymph and chyle, continues throughout life. New corpuscles never appear to be produced from the germs of old ones; when a corpuscle is past its perfection, it degenerates, and probably liquefies. The changes of such degeneration have not been clearly seen in mammalian corpuscles; but they are probably nearly similar to what occur in those of fish and reptiles, in which the old and degenerate corpuscles appear perfectly white and pellucid (not shaded or granular, like the lymph-corpuscles), smaller than they were, and, in some instances, cracked, or as if eroded. The nuclei appear to degenerate with the cells, but, because of their darker and harder outlines, remain longer distinct, and often look like free nuclei, unless the dim cell-wall round them be carefully searched for. But in this process no germ for a new corpuscle issues from the transient cell. Every new corpuscle forms itself in and from the materials of the lymph and chyle, and is perfected in the blood; and the blood is maintained by constant repetitions of this process. Herein, also, is provision for the welfare of the body; for, if the blood corpuscles were, like many cells, derived from germs formed in their predecessors, then every loss of blood would involve the loss, not only of the corpuscles escaping at the time, but of all those that, in after time, should have descended from the lost ones and their germs. But new blood being made from lymph and chyle, its losses to any amount can be repaired, provided the processes for the formation of those fluids are not disturbed.

The development of fibrine appears to proceed commensurately with that of the second set of corpuscles. In the earliest state of the chyle, no fibrine exists; but when chyle-corpuscles are formed, the fluid in which they float is spontaneously coagulable; and the

brine, whose existence is thus proved, appears to increase as the hyle proceeds onwards to the blood, and passes through the lacteal glands. Yet, in the most perfect chyle and lymph the brine is less abundant, and coagulates less firmly than in the blood: we may therefore assume that its development, like that of the corpuscles, is perfected in the blood itself.

From what has been said, it will have appeared that when the blood is once formed, its *growth* and *maintenance* are effected by the constant repetition of the development of new portions. In the same proportion as the blood yields its materials for the maintenance and repair of the several solid tissues, and for secretions, so are new materials supplied to it in the lymph and chyle, and, by development, made like it. The part of the process which relates to the formation of new corpuscles and fibrine has been described; but it is probably only a small portion of the whole process; for the assimilation of the new materials to the blood must be perfect, in regard to all those immeasurably minute particulars by which the blood is adapted for the nutrition of every tissue, and the maintenance of every peculiarity of each. How precise the assimilation must be for such an adaptation, may be conceived from some of the cases in which the blood is altered by disease, and, by assimilation, is maintained in its altered state. For example, by the insertion of vaccine matter, the blood is for a short time manifestly diseased; however minute the portion of virus, it affects and alters, in some way, the whole of the blood. And the alteration thus produced, inconceivably slight as it must be, is long maintained; for, even very long after a successful vaccination, a second insertion of the virus may have no effect, the blood being no longer amenable to its influence, because the new blood, formed after the vaccination, is made like to the blood as altered by the vaccine virus: in other words, the blood exactly assimilates to its altered self the materials derived from the lymph and chyle. So, in all probability, are maintained the morbid states of the blood which exist in syphilis, and many other chronic diseases: the blood, once inoculated, retaining, by the exactness of its assimilation, the taint which it received, though after a time, it may not have in it one of the particles on which the taint first passed. In health, we cannot see the precision of the adjustment of the blood to the tissues; but we may imagine it from the small influences by which, as in vaccination, it is disturbed, and we may be sure that the new blood is as perfectly assimilated to the healthy standard, as, in disease, it is assimilated to the most minutely altered standard.[1]

The assimilation of the blood is probably effected, essentially and finally, by the formative power (see p. 38) which the blood

[1] Corresponding facts in relation to the maintenance of the tissues by assimilation will be mentioned in the chapter on NUTRITION.

possesses in common with the solid tissues. But it is ministered to and assisted by the actions of other parts; as, 1st, the digestive and absorbent systems, with probably the liver, and most or all of the vascular glands, whose especial office is to prepare materials, not only enough, but exactly fit to form the new blood; and, 2dly, the excretory organs, through which the blood separates from itself materials which are refuse, such as the waste substance of the tissues, the urea, carbonic acid, &c., or are unfit to form part of its essential constituents, such as some of the materials taken for food and drink, and absorbed by the bloodvessels of the digestive canal without being formed into chyle. But, 3dly, the precise constitution of the blood is adjusted by the balance of the nutritive processes for maintaining the several tissues, so that none of the materials appropriate for the maintenance of any part may remain in excess in the blood. Each part, by taking from the blood the materials it requires for its maintenance is, as Treviranus observed (lxviii. bd. i. p. 401), in the relation of an excretory organ to all the rest. For example, if the muscles did not take materials for their nutrition, there might be an excess of fibrine and their other constituents in the blood; if the bones did not do so, the salts of lime would be in excess, and so on.[1]

The formative power by which the blood maintains itself is, perhaps, inherent in its whole substance. No sufficient reason appears for considering that it belongs to the corpuscles more than to any of the other highly organic constituents of the blood; neither is there any evidence for determining the particular functions of the corpuscles; only, it is probable that they help in the formation of the fibrine and other appropriate materials for the nutrition of the tissues by acting like gland-cells, that is, by forming or elaborating in their cavities materials which they may discharge when perfect. (See SECRETION.) Both white and red corpuscles may do this, but the red ones more perfectly than the white; since, as a general rule, rudimentary parts have the same function as the perfect parts into which they are developed, but discharge that function with less power.

The *purpose* of the blood thus developed and maintained appears, in the perfect state, to be threefold; namely, 1st, to provide materials appropriate for the nutrition and maintenance of all the parts of the body; 2d, to convey to the several parts oxygen, whether for the discharge of their functions, or for combination with their refuse matters; 3d, to bring from the same parts those refuse matters, and convey them to where they may be discharged. The first is the principal and essential purpose of the blood; the second and third are subordinate purposes, which the blood discharges, as

[1] See further on this subject, lxxi. vol. xxxix. p. 938, and succeeding Lectures.

rere, by the way, and which will be considered in future chap-
s.

Of the first purpose little more is known than that the blood does
ovide the materials for the maintenance of the body; and that
ey are not all in the blood in the same chemical compounds as
ey form in the tissues. Gelatine, for example, which forms so
rge a part of the tissues, does not exist in the blood, and must
erefore be formed from some of its albuminous or proteine
mpounds while the tissues in which it is found are being de-
loped.

It may be observed that the changes which materials taken from
e blood and forming tissues undergo, though always processes of
evelopment in regard to structure, are sometimes degenerations
a chemical sense. The case of the gelatinous tissues is an
ample of this; however highly organized their structure, their
hemical composition is lower than that of the blood, gelatine
eing, as Dr. Prout has shown (xxi. p. 455), the least remote from
organic matter of any of the nitrogenous animal compounds.
hus, the providing of materials for the gelatinous tissues may be
garded as the lowest part of this office of the blood; the highest
, probably, the provision for the nervous and animal muscular
ystems. To these, and especially to the brain, the development
f the blood appears to be peculiarly adjusted. Thus, in the In-
ertebrata that have blood, the observations of Mr. Wharton Jones
xliii. 1846) show that the blood-corpuscles are not developed
eyond the stage which the lymph-corpuscles commonly attain in
he oviparous Vertebrata, though, up to that stage, and in it, they
re very similar to the lymph-corpuscles. Among the Vertebrata,
he Branchiostoma, as a connecting link between the two classes,
ppears to have the same form of blood-corpuscles as the Inverte-
rata; but in other fish we find, coincidently with the great ad-
ance in the development of a brain and spinal cord, the introduc-
ion of a proportionally larger quantity of blood, and of red cor-
uscles formed by a further development of such corpuscles as are
he most perfect in the Invertebrata. In the transition from fish
o reptiles, the greater development of the brain is associated with
general further increase in the quantity and velocity of the blood;
nd in that from reptiles to birds with a yet much larger increase
n its quantity and velocity, an augmentation of the proportion of
hrine, and a great multiplication of blood-corpuscles with reduc-
ion of their size. Lastly, with the greater development of the
rain in Mammalia, we find the development of the blood-corpus-
les into a higher form than they have in any other Vertebrata:
or, though the nucleated cell is commonly regarded as a higher
evelopment than the cell without a nucleus, yet since, in the blood
f the mammalian embryo, the latter supersedes the former, and is

adapted to the general advance of development, we may be sure that, in this instance at least, the cell without a nucleus is the higher form.

Thus it appears that in the same proportion as animals occupy a higher position in the scale of beings, so have they both a larger quantity and a higher quality of blood. Their position in the scale is determined by the development of the central nervous system, in adaptation to which, more or less directly, the other systems relating to the life of the individual are adjusted. The adjustment of the characters of the organic life to the central nervous system is effected through the intervention of the blood, to the formation of which all the organs of that life minister, and which we may, therefore, regard as the highest member of the parts concerned in the organic life, in the same sense as we regard the brain as the highest of the organs of the animal life. And this eminence of the blood is shown, first, by its chemical composition, which, as we have seen, is more highly organic than that of the greater part of the tissues; second, by the time at which it first appears in the embryo, in which, as the brain and spinal cord precede, in their rudiments, the other and subordinate organs of animal life, so the blood appears before any of the persistent organs of the organic life; third, by the complexity and number of the processes through which it is elaborated, including all those the history of which is now to be traced till we come to that of the Nervous system.

CHAPTER V.

CIRCULATION OF THE BLOOD.

THE purposes which have been assigned to the blood, those, namely, of conveying oxygen and nutritive materials to the several parts of the body, and of carrying away from them to excretory organs their refuse matters—require that it should be constantly moving through all the parts, and, at certain periods, should be exposed to the atmosphere in order that it may imbibe oxygen, and emit carbonic acid and water, the substances into which the principal refuse matter is combined. To this end it is provided, in man and all warm-blooded animals, that all the blood which has passed once through the several parts of the body, shall traverse the lungs, and be exposed to the atmosphere before it again takes the same course. This is effected by what is called a double circulation, or, more properly, a single complete circulation in two nearly separate

organs for which are, a heart with two separated com-
or sides, and arteries and veins so connected with each
it of the heart, that the arteries proceeding from the
ad to the veins belonging to the other. The course
nich blood moves in such a circulation may be thus
ribed. (Fig. 18.) Commencing, we will suppose, at the
le of the heart, blood is impelled
aorta and along its successive
he *systemic arteries*, through which
gans of the body, except the finer
the lungs, derive all their blood.
hese arteries it is conveyed into the
pillaries, the minute vessels which
ediately between the arteries and
very part, and in which the blood
it most nearly into contact with
substance of the organs. From
sses into the *systemic veins*, through
trunks of which, the *venæ cavæ*, it
the right auricle, and thence into
ventricle of the heart. This com-
at is called the *systemic circulation*,
ic or general part of the circulation.
ght ventricle, the blood enters the
y or lesser circulation, in which it
om the right ventricle through
onary artery and its branches in the
the capillaries, in which it is brought
o the atmosphere. From the pul-
apillaries the blood enters, in con-
treams, the pulmonary veins, which
to the left auricle, whence, having
ersed the pulmonary part of the
n, it passes again into the left ven-
here, in the case here supposed, it
i its course.

Fig. 18.

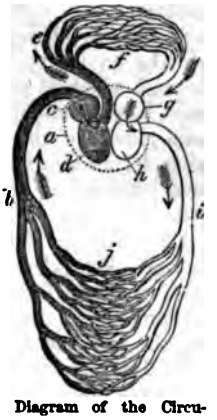


Diagram of the Circulating Apparatus in Mammals and Birds: *a*, the heart containing four cavities; *b*, vena cava, delivering venous blood into *c*, the right auricle; *d*, the right ventricle propelling venous blood through *e*, the pulmonary artery, to *f*, the capillaries of the lungs; *g*, the left auricle, receiving the aerated blood from the pulmonary vein, and delivering it to the left ventricle, *h*, which propels it through the aorta, *i*, to the systemic capillaries *j*, whence it is collected by the veins, and carried back to the heart through the vena cava, *b*.

lood in the left ventricle is arterial
2, &c.), and charged with oxygen
r proportion than carbonic acid, as
ith materials for the supply of the
So it remains in all the systemic
but in the systematic capillaries it
i portions of those materials, and its oxygen is, in great
consumed in uniting with the hydro-carbonous and other
s which enter the bloodvessels from the refuse matter of
s. Thus the blood acquires the venous characters; and

in this state it traverses the systemic veins, the right side of the heart, and the pulmonary arteries; but in the pulmonary capillary vessels, emitting carbonic acid and water, and imbibing oxygen, it becomes again arterial, and so passes on to the left ventricle.

A subordinate kind of circulation is inserted in the liver, and is called the *portal circulation*. The veins belonging to that part of the systemic vessels which are appropriated to the organs of digestion, form a common trunk called *vena portæ;* and this, instead of joining at once with the other main trunks of the systemic veins, enters the substance of the liver. There the vena portæ, branching like an artery, carries its share of the blood into capillaries, through which it passes into the hepatic veins, then goes through their largest branches into the vena cava inferior, one of the two main trunks of the systemic venous system, where the portal circulation terminates by mingling its blood with that which in the vena cava inferior has nearly reached the end of the systemic circulation.

The principal force provided for constantly moving the blood through this course is that of the muscular substance of the heart; other assistant forces are those of the elastic walls of the arteries, the pressure of the muscles among which some of the veins run, and the movements of the walls of the chest in respiration. The right direction of the blood's course is determined and maintained by valves placed between each auricle and ventricle of the heart, at the orifices of communication between the ventricles and the main arterial trunks, and in most of the veins; which valves open to permit the movement of the blood in the course described, but close when any force tends to move it in the contrary direction. We shall consider separately each member of the system of organs for the circulation: and first—

THE ACTION OF THE HEART.

The heart's action in propelling the blood consists in the successive alternate contractions and dilatations of the muscular walls of its two auricles and two ventricles. The auricles contract simultaneously; so do the ventricles; their dilatations, also, are severally simultaneous; and the contractions of the one pair of cavities are synchronous with the dilatations of the other.

The description of the action of the heart may best be commenced at that period in each action which immediately precedes the beat of the heart against the side of the chest, and by a very small interval more precedes the pulse at the wrist. For at this time, which corresponds with the pause between the two sounds of the heart, the whole heart is in a passive state; the walls of both auricles and ventricles are relaxed, and their cavities are being

lilated. The auricles are gradually filling with blood flowing into them from the veins; and a portion of this blood passes at once through them into the ventricles, the opening between the cavity of each auricle and that of its corresponding ventricle being, during all the pause, free and patent. The auricles, however, receiving more blood than at once passes through them to the ventricles, become, near the end of the pause, fully distended; then, in the end of the pause, they contract and empty their contents into the ventricles. The contraction of the auricles is sudden, and very quick; it commences at the entrance of the great veins into them, and is thence propagated towards the auriculo-ventricular opening; but the last part which contracts is the auricular appendix. The effect of this contraction of the auricles is to propel nearly the whole of their blood into the ventricles. The reflux of blood into the great veins is hindered by the simultaneous contraction of the muscular coats with which they are provided for some distance before their entrance into the auricles; a contraction which, however, is not so complete but that a small quantity of blood does regurgitate, *i. e.*, flow backwards into the veins, at each auricular contraction. The effect of this regurgitation from the right auricle is limited by the valves at the junction of the subclavian and internal jugular veins, beyond which the blood cannot move backwards; and the coronary vein is preserved from it by a valve at its mouth.

The blood which is thus driven, by the contraction of the auricles, into the corresponding ventricles, being added to that which had already flowed into them during the heart's pause, is sufficient to complete the distension of the ventricles. Thus distended, they immediately contract; so immediately, indeed, that their contraction looks as if it were continuous with that of the auricles. They contract much more slowly than the auricles, and simultaneously in every part, the whole wall of each ventricle being drawn up uniformly towards the origin of the artery at its base, diminishing the cavity in every diameter, but especially in length, so that the heart assumes a shorter and more globular form than it had in the relaxed and distended state of the ventricles. In this complete and uniform contraction, the ventricles probably always thoroughly empty themselves, differing in this respect from the auricles, in which, even after their completest contraction, a small quantity of blood remains. The form and position of the fleshy columns on the internal walls of the ventricle appear, indeed, especially adapted to produce this obliteration of their cavities during their contraction; and the completeness of the closure may often be observed on making a transverse section of a heart shortly after death, in any case in which the contraction of the *rigor mortis* is very marked. In

such a case only a central fissure may be discernible to the eye in the place of the cavity of each ventricle.

At the same time that the walls of the ventricles contract, the fleshy columns contract also, and draw away the auriculo-ventricular valves from the internal surface of the ventricles against which they had lain while the blood was flowing into the ventricles. The blood thus passes beneath or behind the valves, and, being pressed by the contracting walls of the ventricles, pushes the valves upwards and inwards, and brings their margins into apposition, so that they close the auriculo-ventricular openings, and prevent the backward passage of the blood into the auricles. The whole force of the ventricular contraction is thus directed to the propulsion of the blood through their arterial orifices. During the time which elapses between the end of one contraction of the ventricles and the commencement of another, the communication between them and the great arteries—the aorta on the left side, the pulmonary artery on the right—is closed by the three semilunar valves situated at the orifice of each vessel. But the force with which the current of blood is propelled by the contraction of the ventricle separates these valves from their contact with each other and presses them back against the sides of the artery, making a free passage for the stream of blood. Then, as soon as the ventricular contraction ceases, the elastic walls of the distended artery recoil, and by pressing the blood behind the valves force them down towards the centre of the vessel, and spread them out so as to close the orifice and prevent any of the blood flowing back into the ventricles.

As soon as the contraction of the auricles is completed, they begin again to dilate, and to be filled again with blood which flows into them in a steady stream through the great venous trunks. They are thus filling during all the time in which the ventricles are contracting; and the contraction of the ventricles being ended, they also again dilate and receive again the blood that flows into them from the auricles. By the time that the ventricles are thus from one third to two-thirds full, the auricles are distended; these, then suddenly contracting, fill up the ventricles as already described. Thus the action of the auricles consists in a succession of quick contractions and slow dilatations; that of the ventricles in a succession of contractions and dilatations of nearly equal length. Of the period occupied by a complete action of the heart, the auricles are engaged for about one-eighth in contraction, and seven-eighths in dilating and receiving blood; while the ventricles are occupied for one-half in contracting, and the other in dilating.

The following table will explain the order of the actions already described, and their coincidence, with the sounds and impulse of the heart, of which we shall next speak. It supposes the period occu-

ed by a complete set of the actions of the heart to be divided nto eight parts, and if the case be taken of a person with a pulse eating sixty times in a minute, these parts may represent eighths f a second.

	Eighths of a second.	
st part of the pause . .	1	Aur. contracting: ventr. distended.
st sound and impulse . .	4	Ventr. contracting: aur. dilating.
d sound	2	Ventr. dilating: aur. dilating.
Pause	1	Ventr. dilating: aur. distended.

Action of the Valves of the Heart.

The periods in which the several valves of the heart are in action may be connected with the foregoing table; for the auriculo-ventricular valves are closed, and the arterial valves are open during the whole time of the ventricular contraction; while, during the dilatation and distension of the ventricles the latter valves are shut, the former open. Thus the valves are all alternately open and shut for nearly equal periods of time; and each half or side of the heart, through the action of its valves, may be compared with a kind of forcing pump, like the common enema-syringe with two valves, of which one admits the fluid on raising the piston, but is closed again when the piston is forced down; while the other opens for the escape of the fluid, but closes when the piston is raised, so as to prevent the regurgitation of the fluid already forced through it. The ventricular dilatation is here represented by the raising up of the piston; the valve thus admitting fluid represents the auriculo-ventricular valve, which is closed again when the piston is forced down, *i. e.*, when the ventricle contracts, and the other, *i. e.*, the arterial, valve opens.

The *arterial, semilunar,* or *sigmoid* valves (Fig. 19) are, as

Fig 19.

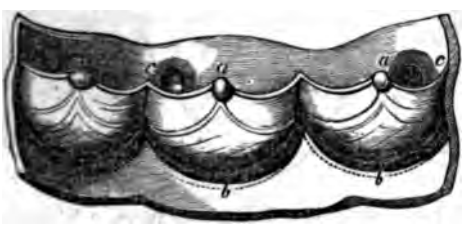
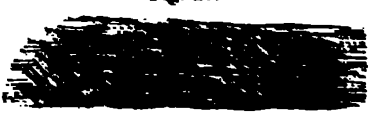


Diagram of the semilunar valves of the aorta (after Morgagni). *a.* Corpus Arantii on the free border. *b.* Attached border. *c.* Orifices of the coronary arteries.

already said, brought into action by the pressure of the arterial blood forced back towards the ventricles, when the elastic walls of

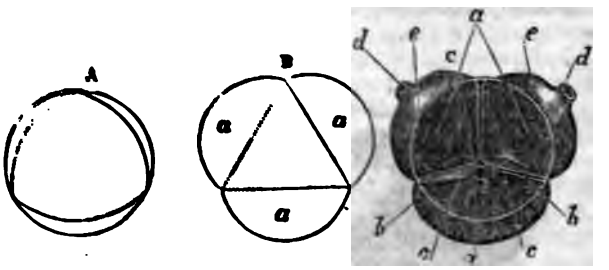
the arteries recoil after being dilated by the blood propelled into them in the previous contraction of the ventricle. The dilatation of the arteries is, in a peculiar manner, adapted to bring the valves into action. The lower borders of the semilunar valves are attached to the inner surface of a tendinous ring, which is, as it were, inlaid, at the orifice of the artery, between the muscular fibres of the ventricle, and the elastic fibres of the walls of the artery (Fig. 20). The tissue of this ring is tough, and does not admit of extension under such pressure as it is commonly exposed to; the valves are equally inextensile, being formed of tough, close-textured, fibrous tissue, with strong interwoven cords, and covered with epithelium. Hence, when the ventricle propels blood through the orifice and into the canal of the artery, the lateral pressure which it exercises is sufficient to dilate the walls of the artery, but not enough to stretch in an equal degree, if at all, the unyielding valves and the ring to which their lower borders are attached. The effect, therefore, of each such propulsion of blood from the ventricle is, that the wall of the first portion of the artery is dilated into three pouches behind the valves, while the free margins of the valves, which had previously lain in contact with the inner surface of the artery (as at A, Fig. 21) are drawn inwards towards its centre

Fig. 20.



Fibrous tissue of a semilunar valve beneath the endocardium.

Fig. 21.



Sections of aorta, to show the action of the semilunar valves. A is intended to show the valves, represented by the dotted lines, in contact with the arterial walls, represented by the continuous outer line. B (after Hunter) shows the arterial wall distended into three pouches (*a*); and drawn away from the valves which are straightened into the form of an equilateral triangle, as represented by the dotted lines. C (after Retzius, cxii.) shows the margins of the valves when in action; *a*, the pouches between the valves and the arterial wall; *b*, the apposed edges; *c*, the apposed surfaces of the valves; *d*, mouths of coronary arteries; *e*, cut edge of aorta.

(Fig. 21, B). Their positions may be explained by the following diagrams, in which the continuous lines represent a transverse section of the arterial walls, the dotted ones the edges of the valves, first, when the valves are in contact with the walls (A), and, secondly, when the walls being dilated the valves are drawn away from them (B).

This position of the valves and arterial walls is retained so long as the ventricle continues in contraction; but, as soon as it relaxes, and the dilated arterial walls can recoil by their elasticity, they press the blood as well towards the ventricles as onwards in the course of the circulation. Part of the blood thus pressed back lies in the pouches (*a*, Fig. 21, B) between the valves and the arterial walls; and the valves are by it pressed together till their margins meet in three lines radiating from the centre to the circumference of the artery, as in C, Fig. 21.

The contact of the valves in this position, and the complete closure of the arterial orifice, are secured by a peculiar construction of their borders. Among the cords which are interwoven in the substance of the valves, are two of greater strength and prominence than the rest; of which one extends along the free border of each valve, and the other forms a double curve or festoon just below the free border. Each of these cords is attached at its ends to the outer angles of its valve, and in the middle to the corpus Arantii, a small mass of fibrous tissue at the centre of the border of each valve; they thus inclose a space from a line to a line and a half in width, in which space the substance of the valve is much thinner and more pliant than elsewhere. When the valves are pressed down, all these parts or spaces of their surfaces come into contact, and the closure of the arterial orifice is thus secured by the apposition not of the mere margins and thin edges of the valves, but of all those parts of the surfaces of each which lie between the free edges and the cords next below them. (See Fig. 21, C, *c*.) These parts are firmly pressed together, and the greater the pressure that falls on them, the closer and more secure is their apposition. The corpora Arantii meet at the centre of the arterial orifice when the valves are down, and they probably assist in the closure; but they are not essential to it, for, not unfrequently, the valves of the pulmonary artery have none, but are extended in larger, thin, flapping margins. In this form of valves, also, the inlaid cords are less distinct than in those with corpora Arantii; yet the closure by contact of their surfaces is not less secure.

The *auriculo-ventricular valves*, like those already described, secure the closure of the orifices at which they are placed by the contact of parts of their surfaces; but in most other respects their mode of action is peculiar. The valve between the right auricle and ventricle is named *tricuspid*, because it presents three principal cusps

or pointed portions, and that between the left auricle and ventricle *bicuspid*, or *mitral*, because it has two such portions. But in both valves there is between each two principal portions a smaller one; so that more properly, the tricuspid may be described as consisting of six, and the mitral of four, portions. Each portion is of triangular form, its apex and sides lying free in the cavity of the ventricle, and its base being fixed to a tendinous ring, which encircles the orifice between the auricle and ventricle, and receives the insertions of the muscular fibres of both. In each principal portion may be distinguished a middle-piece, extending from its base to its apex, and including about half its width; this piece is thicker, and much tougher and tighter than the border-pieces which are attached loose and flapping at its sides.

While the bases of the several portions of the valves are fixed to the tendinous rings, their ventricular surfaces and borders are fastened by slender *tendinous cords* to the walls of the ventricles or to muscular columns or processes (*carneæ columnæ*) projecting from the walls into the cavities of the ventricles. In each ventricle there are as many of these columns as there are principal portions in the corresponding valve. Of the tendinous cords, besides some which pass from the walls of the ventricle and the fleshy columns to the tendinous ring, there are some, of principal strength, which pass from the same parts to the edges of the middle pieces of the several chief portions of the valve. The ends of these cords are spread out in the substance of the valve, giving its middle-piece its peculiar strength and toughness; and from their sides numerous other more slender and branching cords are given off, which are attached all over the ventricular surface of the adjacent border-pieces of the principal portions of the valves, as well as to those smaller portions, which have been mentioned as lying between each two principal ones. Moreover, the muscular columns are so placed, that, from the summit of each, tendinous cords may proceed to the adjacent halves of two of the principal divisions, and to one intermediate or smaller division of the valve.

These valves are brought into action at the instant in which the contraction of the ventricles begins. When not in action, all their portions probably lie close to the ventricular walls; but the contraction of the fleshy columns, being simultaneous with that of the walls of the ventricles, draws out the several portions of the valves as soon as ever the ventricle begins to contract. The arrangement just mentioned, in which each column is connected with two of the principal and one of the intermediate divisions of the valve, further secures that the contraction of the columns shall approximate all the several portions of the valve, bringing them towards the centre of the orifice they are to close. Then, as the contracting walls of the ventricles press on the blood, the valves are pressed up by it

towards the auriculo-ventricular orifices, till their free edges and parts of their borders come into contact. In this position they are held secure, even though the form and size of the orifice and the ventricle may change during the continued contraction; for the border-pieces are held by their mutual apposition and the equal pressure of the blood on their ventricular surfaces; and the middle pieces are secure by their great strength, and by the attachment of the tendinous cords along their margins, these cords being always held tight by the contraction of the muscular columns. A peculiar advantage, derived from the projection of these columns into the cavity of the ventricle, seems to be that they prevent the valve from being everted into the auricle; for, when the ventricle contracts, and the parts of its walls to which, through the medium of the columns, the tendinous cords are fixed, approach the base of the heart and the auriculo-ventricular orifices, there would be a tendency to slackness of the cords, and the valves might be everted, if it were not that while the wall of the ventricle is drawn towards the orifice, the end of the simultaneously-contracting fleshy column is drawn away from it, and the cords are held tight.

What has been said applies equally to the auriculo-ventricular valves on both sides of the heart, and of both alike the closure is generally complete every time the ventricles contract. But in some circumstances the closure of the tricuspid valve is not complete, and a certain quantity of blood is forced back into the auricle; and, since this may be advantageous, by preventing the over-filling of the vessels of the lungs, it has been called the *safety-valve action* of this valve (Hunter, Wilkinson King). The circumstances in which it usually happens are those in which the vessels of the lung are already full enough when the right ventricle contracts, as, *e. g.*, in certain pulmonary diseases, in very active exertion, and in great efforts. In these cases, perhaps because the right ventricle cannot contract quickly or completely enough, the tricuspid valve does not completely close, and the regurgitation of blood may be indicated by a pulsation in the jugular veins synchronous with that in the carotid arteries.

Sounds and Impulse of the Heart.

When the ear is placed over the region of the heart, two sounds may be heard at every beat of the heart, which follow in quick succession, and are succeeded by a pause or period of silence. The first sound is dull and prolonged; its commencement coincides with the impulse of the heart, and just precedes the pulse at the wrist. The second is a shorter and sharper sound, with a somewhat flapping character, and follows close after the arterial pulse. If the period of time occupied by the two sounds and by the subsequent pause—which together constitute the *rhythm* of the

heart—be divided into four equal parts, the first sound, and the very short interval between it and the second, will be found to occupy the first two parts, or half the period of the rhythm; the second sound rather less than another part, and the pause rather more than the fourth part.

The events which correspond, in point of time, with the first sound, and which may therefore contribute to its production, or to morbid changes in its characters, are (as expressed in the table at p. 75) the contraction of the ventricles, the first part of the dilatation of the auricles, the closure of the auriculo-ventricular valves, the openness of the semilunar valves, and the propulsion of blood into the arteries. The sound is succeeded, in about one-thirtieth of a second, by the pulsation of the facial artery, and in about one-sixth of a second, by the pulsation of the arteries at the wrist. The second sound, in point of time, immediately follows the cessation of the ventricular contraction, and corresponds (as the same table shows) with the closure of the semilunar valves, the continued dilatation of the auricles, the commencing dilatation of the ventricles, and the opening of the auriculo-ventricular valves. The pause immediately follows the second sound, and corresponds in its first half with the completed distension of the auricles, and in its second with their contraction, and the distension of the ventricles, the auriculo-ventricular valves being all the time open, and the arterial valves closed.

The results of numerous investigations into the *cause of the sounds of the heart* have shown that the *first* sound is chiefly due to the contraction of the muscular fibres of the ventricles, which, like the contraction of muscle in other parts, is accompanied with the production of a certain amount of sound. In the case of the ventricular contraction, the sound is rendered peculiarly loud and distinct by a large mass of fibres being simultaneously in action, and by the force with which their contraction takes place. The sound emitted by them is rendered clearer and more distinct by the tense state in which the auriculo-ventricular valves are held during the continuance of the ventricular contraction; for, in this condition, they probably vibrate, like sounding-boards, with the vibrations communicated to them through the tense tendinous cords that attach them to the vibrating and sounding muscles. Thus the valves may increase the sound produced by the muscles; and, besides, it is not improbable that the suddenness with which they are put on the stretch at the commencement of the ventricular contraction may be productive of a certain amount of sound originating in themselves. This supposition is supported by the fact observed by Valentin (iv. Bd. i. p. 427), that if a portion of a horse's intestine, tied at one end, be moderately filled with water without any admixture of air, and have a syringe containing water

fitted to the other end, the first sound of the heart is exactly imitated by forcing in more water, and thus suddenly rendering the walls of the intestine more tense.

Some share in the production or modification of the first sound of the heart is probably due, also, to the impulse of the apex against the walls of the chest; for, when this impulse is prevented, as in cases of congenital or artificial exposure of the heart, the intensity of the first sound is said to be diminished. The sudden pressing back of the semilunar valves, and the rush of blood through the orifices of the aorta and the pulmonary artery may also, in some measure, affect the first sound. These circumstances, however, must be regarded as only secondary conditions in the production of a sound which has its source in the muscular contraction of the ventricles; and they would have scarcely deserved notice, but that, in cases of disease, alterations in them may change the character of the first sound.

The fact that the sound emitted by the contraction of a morbidly enlarged and thickened ventricle is less clear and loud than that produced by a healthy one, may seem opposed to the above explanation; for the inference is natural that increase in the bulk of a muscle will be accompanied with increase in the sound given out by it during its contraction. But it may be that, in the contraction of an hypertrophied ventricle, the sound emitted by the superficial fibres alone is conveyed to the ear; that produced by the contraction of the deeper ones being obscured by the thickness of the tissue through which it has to pass in its transit to the surface. It is probable, also, that the contraction of the fibres of an hypertrophied ventricle is not quite simultaneous; and this may account for the first sound in such cases being unusually prolonged, and less loud and distinct. When, however, the ventricular walls are unusually thin, the first sound is peculiarly loud and clear, because the sound emitted by the contraction of every fibre is transmitted to the ear, and because all the fibres contract simultaneously. The share, also, which the tension of the auriculo-ventricular valves and the passage of the blood through the orifices of the great arteries contribute towards the first sound, is more perceptible in the latter than in the former case, probably because it more readily admits of being transmitted through thin, than through the hypertrophied, walls of a ventricle.

The cause of the *second* sound appears to be more simple than that of the first. It is probably due almost entirely to the sudden tightening of the semilunar valves when they are pressed down across the orifice of the aorta and pulmonary artery; for, of the other events which take place during the second sound, none is calculated to produce sound. The influence of the valves in producing the sound is illustrated by the experiment already quoted

from Valentin, and by others performed on large animals, such as calves, in which the results could be fully appreciated. In these, two delicate curved needles were inserted, one into the aorta and another into the pulmonary artery, below the line of attachment of the semilunar valves; and, after being carried upwards about half an inch, were brought out again through the coats of the respective vessels, so that in each vessel one valve was included between the arterial walls and the wire. Upon applying the stethoscope to the vessels after such an operation, the second sound has ceased to be audible. Disease of these valves, when so extensive as to interfere with their efficient action, also often demonstrates the same fact by modifying or destroying the distinctness of the second sound. The second sound does not continue all the time the semilunar valves are closed, probably because it is only produced by the tightening and soon-ending vibration of the valves.

The contraction of the auricles which takes place in the end of the pause is inaudible outside the chest, but may be heard when the heart is exposed and the stethoscope placed on it, as a slight sound preceding and continued into the louder sound of the ventricular contraction.

The Impulse of the Heart.—At the commencement of each ventricular contraction, the heart may be felt to beat with a shock or *impulse* against the walls of the chest. This impulse is most evident in the space between the fifth and sixth ribs, betweeen one and two inches to the left of the sternum. The force of the impulse, and the extent to which it may be perceived beyond this point, vary considerably in different individuals, and in the same individuals under different circumstances. It is felt more distinctly, and over a larger extent of surface, in emaciated than in fat and robust persons, and more during a forced expiration than in a deep inspiration; for, in the one case, the intervention of a thick layer of fat or muscle between the heart and the surface of the chest, and in the other the inflation of the portion of lung which overlaps the heart, prevents the impulse from being fully transmitted to the surface. An excited action of the heart, and especially an hypertrophied condition of the ventricles, will increase the impulse, while a depressed condition, or an atrophied state of the ventricular walls, will diminish it.

The impulse of the heart is probably the result of several circumstances which, acting in combination, have a tendency to rotate the whole organ from left to right, and to tilt its apex forwards and upwards, so that it is made to strike against the walls of the chest. Apparently the most important of these circumstances is the contraction of the spiral muscular fibres of the ventricles, and especially of certain of these fibres which, according to Dr. Reid (lxxiii. vol. ii. p. 606), arise from the base of the ventricular septum, pass

downwards and forwards, forming part of the septum, then emerge and curve spirally around the apex and adjacent portion of the heart. The general direction of these fibres is from right to left, and the great mass of them pass in at the apex of the left ventricle, and assist in forming the muscular columns within it. The fibres on the front of the heart and on the right side of the left ventricle being much longer than those on the back and left side of it, will contract most, as they all draw up towards the tendinous rings; in their contraction they tend to draw the apex forwards and upwards; and probably, also, by their spiral turning round the apex, they make it rotate slightly from the left towards the right side of the chest. The whole extent of movement thus produced is but slight; the apex of the heart is carried through a curved line of about half an inch in length, at the end of which it touches the intercostal space, and is felt externally. The movement affects the apex of the heart much more than its body and base; their relation to the walls of the chest undergoes little change in the several actions of the heart, and the change is the less perceptible because the tissues that intervene between them and the wall of the chest shift and adapt themselves to their several movements.

The condition which, next to the action of these fibres, contributes most to the occurrence and character of the impulse of the heart is its change of shape; for, during the contraction of the ventricles, it becomes more globular, and bulges so much that, according to Dr. Mitchell (cxvi. Nov. 1844), and M. Kiwisch (lix. 1846), this change alone is sufficient to produce the impression of an impulse when the finger is placed over the bulging portion of the heart, either at the front of the chest or under the diaphragm. The production of the impulse is, perhaps, further assisted by the tendency of the aorta to straighten itself and diminish its curvature when distended with the blood impelled by the ventricle; and, by the elastic recoil of all the parts about the base of the heart, which, according to the experiments of Kürschner (xv. Art. *Herzthatigkeit*), are stretched downwards and backwards by the blood flowing into the auricles and ventricles during the dilatation of the latter, but recover themselves when, at the beginning of the contraction of the ventricles, the flow through the auriculo-ventricular orifices is stopped. But these can be only accessory conditions in the perfect state of things: for the same tilting movement of the heart ensues when its apex is cut off, and no tension or change of form can be produced by the blood. The cause of the impulse must therefore be in the walls of the heart itself; and when the apex of the heart is cut off, and the continuity of most of those fibres, to whose action we have ascribed the impulse in the perfect state of the organ, is destroyed, then we may believe that the fibres remaining in the body and base of the heart, and having the same general spiral di-

rection from right to left and from above downwards, are sufficient to produce a similar tilting movement.

Frequency and Force of the Heart's Action.

The frequency with which the heart performs the actions we have described may be counted by the pulses at the wrist, or in any other artery; for these correspond with the contractions of the ventricles.

The heart of a healthy adult man in the middle period of life acts from seventy to seventy-five times in a minute. The frequency of the heart's action gradually diminishes from the commencement to the end of life, thus:—

In the embryo, the average number of pulses in a minute is	150
Just after birth	from 140 to 130
During the first year	130 to 115
During the second year	115 to 100
During the third year	100 to 90
About the seventh year	90 to 85
About the fourteenth year	85 to 80
In the middle period of life	75 to 70
In old age	65 to 50

In persons of sanguine temperament the heart acts somewhat more frequently than in those of the phlegmatic; and in the female sex more frequently than in the male.

After a meal its action is accelerated, and still more so during bodily exertion or mental excitement; it is slower during sleep. The effect of disease in producing temporary increase or diminution of the frequency of the heart's action is well known. From the observations of several experimenters, it appears that in the state of health, the pulse is most frequent in the morning, and becomes gradually slower as the day advances; and that this diminution of frequency is both more regular and more rapid in the evening than in the morning. It is found, also, that, as a general rule, the pulse, especially in the adult male, is more frequent in the standing than in the sitting posture, and in this than in the recumbent position; the difference being greatest between the standing and the sitting posture. This effect of change of posture is greater as the frequency of the pulse is greater, and accordingly, is more marked in the morning than in the evening. Dr. Guy, by supporting the body in different postures, without the aid of muscular effort of the individual, has proved that the increased frequency of the pulse in the sitting and standing positions is dependent on the muscular exertion engaged in maintaining them; the usual effect of these postures on the pulse being almost entirely prevented when the usually attendant muscular exertion was rendered unnecessary (lviii. Nos. 6 and 7). The effect of food, like that of change of posture, is

greater in the morning than in the evening. According to Parrot, the frequency of the pulse increases in a corresponding ratio with the elevation above the sea; though it must be stated that other observers have found no such difference from change of elevation. (See especially Mr. R. H. Hunter, lxxi. Aug. 9, 1850.)

In health, there is observed a nearly uniform relation between the frequency of the pulse and of the respirations; the proportion being, on an average, one of the latter to three or four of the former. The same relation is generally maintained in the cases in which the pulse is naturally accelerated, as after food or exercise: but in disease this relation usually ceases to exist. In many affections accompanied with increased frequency of the pulse, the respiration is, indeed, also accelerated, yet the degree of its acceleration bears no definite proportion to the increased number of the heart's actions: and in many other cases the pulse becomes more frequent without any accompanying increase in the number of respirations; or, the respiration alone may be accelerated, the number of pulsations remaining stationary, or even falling below the ordinary standard. (On the whole of this subject, the article *Pulse*, by Dr. Guy, in the Cyclopædia of Anatomy and Physiology, may be advantageously consulted.)

The *force* with which the left ventricle of the heart contracts is about double that exerted by the contraction of the right: being equal (according to Valentin) to about 1-50th of the weight of the whole body, that of the right being equal only to 1-100th of the same (iv. Bd. 1, p. 415, &c.). This difference in the amount of force exerted by the contraction of the two ventricles, results from the walls of the left ventricle being about twice as thick as those of the right. And the difference is adapted to the greater degree of resistance which the left ventricle has to overcome, compared with that to be overcome by the right: the former having to propel blood through every part of the body, the latter only through the lungs.

The *capacity* of the two ventricles is probably exactly the same. It is difficult to determine with certainty how much this may be; but, taking the mean of various estimates, it may be inferred that each ventricle is able to contain, on the average, about three ounces of blood, the whole of which is impelled into their respective arteries at each contraction. The capacity of the auricles is rather less than that of the ventricles: the thickness of their walls is considerably less. The latter condition is adapted to the small amount of force which the auricles require, in order to empty themselves into their adjoining ventricles; the former, to the ventricles being partly filled with blood before the auricles contract.

The force exercised by the auricles in their contraction has not been calculated. Neither is it known with what amount of

force either the auricles or the ventricles dilate: but there is no evidence for the opinion that in their dilatation they can materially assist the circulation by any such action as that of a sucking-pump, or a caoutchouc bag, in drawing blood into their cavities. That the force the ventricles exercise in dilatation is very slight was proved by Oesterreicher (c. p. 33). He removed the heart of a frog from the body, and laid upon it a substance sufficiently heavy to press it flat, and yet so small as not to conceal the heart from view; he then observed that during the contraction of the heart the weight was raised, but that during its dilatation the heart remained flat. And the same was shown by Dr. Clendinning, who, applying the points of a pair of spring callipers on the heart of a live ass, found that their points were separated as often as the heart swelled up in the contraction of the ventricles, but approached each other by the force of the spring when the ventricles dilated. Seeing how slight the force exerted in the dilatation of the ventricles is, it has been supposed that they are only dilated by the pressure of the blood impelled from the auricles; but that both ventricles and auricles dilate spontaneously is proved by their continuing their successive contractions and dilatations when the heart is removed, or even when they are separated from one another, and when therefore no such force as the pressure of blood can be exercised to dilate them. By such spontaneous dilatation they at least offer no resistance to the influx of blood, and save the force which would otherwise be required to dilate them.

Cause of the Rhythmic Action of the Heart.

It has been attempted in various ways to account for the existence and continuance of those peculiar rhythmic movements by which the action of the heart is distinguished from that of all the other muscles. By some it has been supposed that the contact of arterial blood with the lining membrane of the left cavities of the heart, and of venous blood with that of the right cavities, furnishes a stimulus, in answer to which the walls of these cavities contract. And they explain the rhythmic order in which these contractions ensue, by supposing that the same act—the systole, which expels the stimulating fluid from the ventricles, causes the auricles to be filled from the veins; and that the contraction of the auricles thereupon induced gives rise, in its turn, to the filling and consequent contraction of the ventricles. But this, and all hypotheses concerning the action of the heart which suppose the necessity of the contact of blood, or any such stimulus, are disproved by the fact that the heart, especially in Amphibia and fishes, will continue to contract and dilate regularly and in rhythmic order after it is removed from the body, completely emptied of blood, and

even placed in a vacuum where it cannot receive the stimulus of the atmospheric air.

The influence of the mind, and of some affections of the brain and spinal cord upon the action of the heart, proves that it is not altogether, or at all times, independent of the cerebro-spinal nervous system. Yet the numerous experiments instituted for the purpose of determining the exact relation in which the heart stands towards this system, have failed to prove that the action is directly governed by the power of any portion of the brain or spinal cord. The results of the experiments are, in many instances, contradictory; but a general conclusion from them may be, that no uniform and decided alteration in the movements of the heart is produced by irritation of any part of either of those nervous centres. Sudden destruction of either the brain or spinal cord alone, or of both together, produces, immediately, a temporary interruption or cessation of the heart's action; but this appears to be only an effect of the *shock* of so severe an injury; for, in some such cases, the movements of the heart are subsequently resumed, and if artificial respiration be kept up, may continue for a considerable time; and may then again be arrested by a violent shock applied through an injury of the stomach. While, therefore, we must admit an indirect or occasional influence exercised by, or through, the brain and spinal cord upon the movements of the heart, and may believe this influence to be the greater the more highly the several organs are developed, yet it is clear that we cannot ascribe the regular determination and direction of the movements to them, in the same way as we may ascribe to the medulla oblongata the power of determining and regulating the involuntary and, in some degree, rhythmical, movements of respiration.

The persistence of the movements of the heart in their regular rhythmic order, after its removal from the body, and their capability of being then re-excited by an ordinary stimulus after they have ceased, prove that the cause of these movements must be resident within the heart itself. And it seems probable, from the experiments and observations of Remak (cxxx. No. ii. 1840), Volkmann (lxxx. 1844, p. 424), Dr. Robert Lee (cxxiii. 1847, and lxxi. vol. xlv. p. 224), and others (see xxv. 1844-5, p. 13), that it may be connected with the existence of numerous minute ganglia of the sympathetic nervous system, which, with connecting nerve-fibres, are distributed through the substance of the heart. These ganglia appear to act as so many centres or organs for the production of motor impulse; while the connecting nerve-fibres unite them into one system, and enable them to act in concert and direct their impulses so as to excite in regular series the successive contractions of the several muscles of the heart. The mode in which ganglia thus act as centres and co-ordinators of nervous power will

be described in the chapter on the NERVOUS SYSTEM; and it will appear probable that the chief peculiarity of the heart, in this regard, is due to the number of its ganglia, and the apparently equal power which they all exercise; so that there is no one part of the heart whose action, more than another's, determines the actions of the rest. Thus, if the heart of a reptile be bisected, the rhythmic successive actions of auricle and ventricle will go on in both halves: we therefore cannot say that the action of the right side determines or regulates that of the left, or *vice versa;* and we must suppose that when they act together in the perfect heart, it is because they are both, as it were, set to the same time. Neither can we say that the auricles determine the action of the ventricles; for, if they are separated, they will both contract and dilate in regular, though not necessarily similar, succession. A fact pointed out by Mr. Malden, shows how the several portions of each cavity are similarly adjusted to act alike, yet independently of each other. If a point of the surface of the ventricle of a turtle's or frog's heart be irritated, it will immediately contract, and very quickly afterwards all the rest of the ventricle will contract: but, in the close of this general contraction, the part that was irritated and contracted first, is slightly distended or pouched out, showing that it was adjusted to contract in and for only a certain time, and that therefore as it began to contract first, so it first began to dilate.[1]

The connection of the action of the heart with the other organs, and the influences to which it is subject through them, are explicable by the connection of its nervous system with the other ganglia of the sympathetic, and with the brain and spinal cord through, chiefly, the pneumogastric nerves. But this influence is proved in a much more striking manner by the phenomena of disease than by any experimental or other physiological observations. The influence of a shock in arresting or modifying the action of the heart—its very slow action after compression of the brain, or injury to the cervical portion of the spinal cord—its irregularities and palpitations in dyspepsia and hysteria—are better evidence for the connection of the heart with the other organs through the nervous system, than any results obtained by experiments. The best of such results are recorded by E. H. Weber (xv. Art. *Muskelbewegung*), who found that the electro-magnetic stimulus applied in the frog to the *bulbus arteriosus*, around which the principal fibres of the sympathetic nerves supplying the heart are placed, accelerated and strengthened the heart's action; but, ap-

[1] The experiment also proves the uniform and simultaneous action of the whole wall of the ventricle, and the advantage thereof; since if one part of the wall ceased to contract before the rest it would be pouched out by the communicated pressure of the blood still compressed by the continuing contraction of the rest of the wall.

to the pulsating part of the vena cava inferior, where are the ipal filaments it derives from the pneumogastric nerves, re- d the action. He is disposed, therefore, to think that, in ral, stimuli conveyed through the sympathetic nerve would erate, and through the pneumogastric would retard, the t's action. The latter conclusion is corroborated by the fact, stated by him, that the heart's action is retarded by stimulus ied to any part between the corpora quadrigemina and poste- part of the fourth ventricle of the brain, or to both trunks of pneumogastric nerves at once, or by division of both pneumo- ric nerves in the necks of Mammalia.

Effects of the Heart's Action.

hat the contractions of the heart supply alone a sufficient force the circulation of the blood appears to be established by these wing facts. 1. When the heart is removed, or the aorta tied, circulation stops abruptly and completely: and the circulation my part may be so arrested by tying its main arteries. 2. gendie found, by dividing transversely all the parts of a limb pt its main artery and vein, that the current through the latter completely and at once controlled by pressure on the former: ough here, as in the former cases, the vessels beyond the ob- ction might have maintained the stream of blood if they had essed any propulsive power. 3. Dr. Sharpey (xciv. vol. lxiii. 0) injected bullock's blood into the thoracic aorta of a dog re- ly killed, after tying the abdominal aorta above the renal ries, and found that, with a force just equal to that by which ventricle commonly impels the blood in the dog, the blood t he injected into the aorta passed in a free stream out of the nk of the vena cava inferior. It thus traversed both the sys- ic and hepatic capillaries; and when the aorta was not tied ve the renals, blood injected under the same pressure flowed ly through the vessels of the lower extremities. A pressure al to that of one and a half or two inches of mercury was, in same way, found sufficient to propel blood through the vessels he lungs.

low this force of the ventricles is applied, directed, and assisted he several orders of vessels will appear in the following sections.

he best special treatises to which the student can refer for details discussions respecting the action of the heart are, the articles rt and *Circulation*, in the Cyclopædia of Anatomy and Physi- y, the Reports of the Medical Section of the British Associa- , in the Medical Gazette, vols. xix. and xxi., and the works of Hunter (i. vol. iii. p. 173), of Dr. Hope (cxvii.), and of Dr. . B. Williams (cxviii).

THE ARTERIES.

For the purpose of explaining the influence of the arteries in the circulation it will be sufficient to consider the walls of an artery as containing, at the most, five distinct layers, or coats, namely, an external, an elastic, a muscular, an internal coat, and an epithelial lining.[1] The *external* coat is constructed of ordinary fibro-cellular tissue, the fibres of which are arranged, for the most part, in a longitudinal direction. It forms a strong, tough investment, which, though capable of extension, appears principally designed to strengthen the walls of the artery, and to guard against their excessive distension from the force of the heart's action. It serves another purpose also in affording a suitable tissue for the ramifications of the *vasa arteriarum*, or nutritive vessels for the supply of the arterial walls. The internal arterial coat (the striated or fenestrated coat of Henle) consists of a very thin and brittle membrane. It possesses little elasticity, and is thrown into folds or wrinkles, when an artery contracts. Its internal surface is lined with a delicate layer of epithelium, which makes it smooth and polished, and furnishes a nearly impermeable surface, along which the blood may flow with the smallest possible amount of resistance from friction.

The elastic and muscular coats are the seats of those properties by which arteries chiefly influence the circulation. Previous to the time of John Hunter, the distinction between these two coats, which constitute the chief thickness of the arterial wall appears to have been overlooked, and it was usual to describe them together as a single tissue under the denomination of the middle, fibrous, or elastic coat. But in the admirable account which Hunter gave of the properties of arteries, proof was afforded of the dissimilarity in structure and function between the inner and outer portions of this supposed single coat. And recent observations have shown the accuracy of his account, and furnished additional facts in confirmation of it. The outer of these two coats is made up almost entirely of fibres of yellow elastic tissues, and constitutes, as Hunter named it, the *elastic* coat. The inner consists of circularly-arranged, pale, flat fibres, which differ in no essential respect from the fibres of organic muscle, such as compose the muscular coat of the stomach and intestines; but are mingled with more filaments of fine elastic tissue. Its chemical characters are equally similar to those of organic muscle. The older analyses, in which the similarity was not detected, were probably made of the walls of the largest arteries in which elastic tissue alone exists. By later analysis, Dr. Retzius

[1] For the best account of these structures see Henle (xxxvii. p. 494), or an abstract of his observations (xxv. 1842, p. 39); also Kölliker (lix. 1847).

. p. 171) has found in this coat a proteine-compound, ıer cellular nor elastic tissue contain; and Dr. Donders 3, p. 67) has proved the same more perfectly. When, rong nitric acid is applied to any compound of proteine, ıth it what is termed xantho-proteinic acid, which, with produces a yellow xantho-proteinate of ammonia. On ıis test, with the requisite cautions, to the coats of blood- found that the muscular arterial coat alone assumed the stic yellow color. The other coats, as well as all the coats emained unchanged in color. He found also that potash he coat of arteries, as on organic muscle, separating its aking them granular, and finally dissolving them. For therefore, the name of *muscular*, applied by Hunter, may ed.

two coats exist in different relative degrees of thickness in arteries; and, in general, are in an inverse ratio to each r the arteries which possess most elastic tissue have the scular tissue, while those whose walls are most muscular eneral the least elastic. In the large arteries, such as the d its main branches, scarcely a trace of the muscular coat ound, nearly the whole thickness of their walls consisting c tissue. But in the arteries farther removed from the ıd of smaller size, the proportionate thickness of the elastic dually diminishes, while, as a general rule, that of the mus- ıat progressively increases. Moreover, in the arteries of organs, probably of those in which the supply of blood is to greater than usual variations in adaptation to fluctuations mount of function they discharge, there is a proportionately development of the muscular coat.

ıe properties which the arteries possess in these two coats, cularity has its seat exclusively in the muscular coat, and y without this coat would present any contraction similar of muscles. But elasticity is a property not exclusively, especially, seated in the elastic coat; rather, all the coats, erhaps the internal, are in some measure elastic, and will ter being distended; and the effect their elasticity produces rther assisted by the elasticity of the tissues around them.

urposes of the elasticity of arteries are chiefly twofold: 1st. s them from the suddenly exerted pressure to which they ected at each contraction of the ventricles. In every such ion, the contents of the ventricles are forced into the more quickly than they can be discharged into and through llaries. The blood, therefore, being for an instant resisted ward course, a part of the force with which it was impelled ed against the sides of the arteries; under this force, which

might burst a brittle tube, their elastic walls dilate, stretching enough to receive the blood, and as they stretch becoming more tense and more resisting. Thus, by yielding, they as it were break the shock of the force impelling the blood, and exhaust it before they are in danger of bursting, through being overstretched. Elasticity is thus advantageous in all arteries, but chiefly so in the aorta and its large branches, which are provided, as already said, with a large quantity of elastic tissue, in adaptation to the great force of the left ventricle, which falls first on them, and to the increased pressure of the arterial blood in violent expiratory efforts.

On the subsidence of the pressure, when the ventricles cease contracting, the arteries are able, by the same elasticity, to resume their former caliber; and in thus doing, they manifest the second chief purpose of their elasticity, that, namely, of equalizing the current of the blood by maintaining pressure on the blood in the arteries during the periods at which the ventricles are at rest or dilating. If some such method as this had not been adopted, if, for example, the arteries had been rigid tubes, the blood, instead of flowing as it does, in a constant stream, would have been propelled through the arterial system in a series of jerks corresponding to the ventricular contractions, with intervals of almost complete rest during the inaction of the ventricles. But, in the actual condition of the arteries, the force of the successive contractions of the ventricles is expended partly in the direct propulsion of the blood, and partly in dilating the elastic arteries; and in the intervals between the contractions of the ventricles, the force of the recoiling and contracting arteries is employed in continuing the same direct propulsion. Of course, the pressure exercised by the recoiling arteries is equally diffused in every direction through the blood, and the blood would tend to move backwards as well as onwards; but all movement backwards is prevented by the closure of the arterial valves, which takes place at the very commencement of the recoil of the arterial walls.

By this exercise of the elasticity of the arteries, all the force of the ventricles is made advantageous to the circulation; for that part of their force which is expended in dilating the arteries is restored in full, according to the law of action of elastic bodies, by which they return to the state of rest with a force equal to that by which they were disturbed therefrom. There is thus no loss of force; but neither is there any gain, for the elastic walls of the artery cannot originate any force for the propulsion of the blood—they only restore that which they received from the ventricles; they would not contract, had they not been first dilated, any more than a spiral spring would shorten itself unless it were first elongated. The advantage of elasticity in this regard is, therefore, not that it

but that it equalizes or diffuses the forces derived from lic contractions of the ventricles. The force with which es are dilated every time the ventricles contract might be received by them in store, to be all given out again in the seeding period of dilatation of the ventricles. It is by lizing influence of the successive branches of every artery engtli, the intermittent accelerations produced in the arte- nt by the action of the heart cease to be observable, and ng stream is converted into the continuous and equable it of the blood which we see in the capillaries and veins. ther purposes served by the elasticity of arteries must not ooked. One is the capacity which the arteries have for g more than the average quantity of blood, both every time ricles contract, and when the supply of blood to the whole any part of it is, for a time, unusually large. In all such e enlargement of the arteries is effected by increase of both ameter and their length; and the elongation appears to be, ly, more considerable than the dilatation. The other pur- rved by the elasticity is, that, by means of it, the arteries bled to adapt themselves to the different movements of the parts of the body.

evidence for the *muscularity* of arteries needs probably to be t length, since, even recently, some physiologists have denied e arterial walls possess any property analogous to muscular tility. We have already referred to Mr. Hunter's account muscular structure of the inner layer of the middle coat of the largest arteries, and to the fact, first observed by Henle, is layer is composed of fibres, in all respects similar to those anic muscles, though mingled with fine elastic filaments. bservation of the action of arteries will show, 1st, The opera- f a contractile power in arteries, essentially distinct from lasticity; and 2dly, the identity of this power with muscular ctility.

en a small artery in the living subject is exposed to the air l, it gradually but manifestly contracts. Hunter (i. vol. iii.) observed that the posterior tibial artery of a dog when laid ecame in a short time so much contracted as almost to pre- he transmission of blood; and the observation has been often ariously confirmed. Simple elasticity could not effect this; er death, when the vital muscular power has ceased, and the nical elastic one alone operates, the contracted artery dilates

en an artery is cut across, its divided ends contract, and the may be completely closed. The rapidity and completeness contraction are different in different animals; they are gene-

rally greater in young than in old animals; and less, apparently, in man than in animals. The contraction is generally increased by the application of cold, or of any simple stimulating substances, or by mechanically irritating the cut ends of the artery, as by pricking or twisting them. Such irritation would not be followed by these effects if the arteries had no other power of contracting than that depending upon elasticity.

The contractile property of arteries continues many hours after death, and thus affords an opportunity of distinguishing it from elasticity. When a portion of an artery, for example, the splenic artery, of a recently killed animal, is exposed, it gradually contracts, and its canal may be thus completely closed: in this contracted state it remains for a time, varying from a few hours to two days; then it dilates again, and permanently retains the same size. If while contracted, the artery be forcibly distended, its contractility is destroyed, and it holds a middle or natural size.

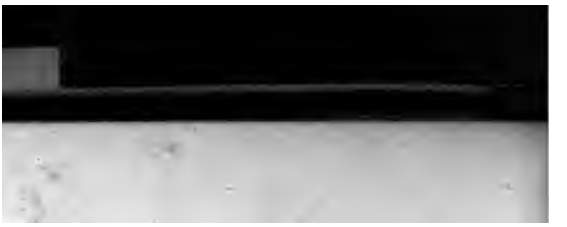
This persistence of the contractile property after death was well shown in an observation of Hunter, which may be mentioned as proving also the greater degree of contractility possessed by the smaller than the larger arteries. Having injected the uterus of a cow, which had been removed from the animal upwards of twenty-four hours, he found, after the lapse of another day, that the larger vessels had become much more turgid than when he injected them, and that the smaller arteries had contracted so as to force the injection back into the larger ones.

The results of an experiment which Hunter made with the vessels of an umbilical cord, prove still more strikingly the long continuance of the contractile power of arteries after death. In a woman delivered on a Thursday afternoon, the umbilical cord was separated from the fœtus, having been first tied in two places, and then cut between, so that the blood contained in the cord and placenta was confined in them. On the following morning, Hunter tied a string round the cord, about an inch below the other ligature, that the blood might still be confined in the placenta and remaining cord. Having cut off this piece, and allowed all the blood to escape from its vessels, he attentively observed to what size the ends of the cut arteries were brought by the elasticity of their coats, and then laid aside the piece of cord to see the influence of the contractile power of its vessels. On Saturday morning, the day after, the mouths of the arteries were completely closed up. He repeated the experiment the same day with another portion of the same cord, and on the following morning found the results to be precisely similar. On the Sunday, he performed the experiment the third time, but the artery seemed then to have lost its contractility, for, on the Monday morning, the mouths of the cut arteries were found open. In each of these experiments there was but little alteration perceived in the orifices of the veins (i. vol. iii. p. 158).

The influence of cold in increasing the contraction of a divided ery has been referred to: it has been shown, also, by Schwann, an experiment on the mesentery of a living toad. Having exded the mesentery under the microscope, he placed upon it a few ops of water, the temperature of which was some degrees lower an that of the atmosphere. The contraction of the vessels soon mmenced, and gradually increased until, at the expiration of ten fifteen minutes, the diameter of the canal of an artery, which at rst was 0.0724 of an English line, was reduced to 0.0276. The teries then dilated again, and at the expiration of half an hour ad acquired nearly the original size. By renewing the application f the water, the contraction was reproduced: in this way the exeriment could be performed several times on the same artery. The veins did not contract. It is thus proved that cold will excite ontraction in the walls of very small, as well as of comparatively arge arteries: it could not produce such contraction in a merely lastic substance; but it is a stimulus to the organic muscular fibres n many other parts, as well as in the arterial coats; as, *e. g.*, in the walls of the bronchi, and the dartos.

Lastly, satisfactory evidence of the muscularity of the arterial coats is furnished by the experiments of Ed. and E. H. Weber (lxxx. 1847, p. 232), and of Professor Kölliker (exc. July, 1850, p. 241), in which they applied the stimulus of electro-magnetism to small arteries. One principal circumstance which induced Müller to deny the muscularity of arteries, was the seeming impossibility of producing contractions in arteries by galvanic and electric stimuli, which excite all true muscular tissues to manifest contraction. An explanation of the failure may be found in the circumstance that, in nearly all the experiments, the arteries examined were of large size, such as the aorta and the carotid, in which there is little or no muscular tissue. The experiments of the Webers were performed on the small mesenteric arteries of frogs; and the most striking results were obtained, when the diameter of the vessels examined did not exceed from 1-7th to 1-17th of a Paris line. When a vessel of this size was exposed to the electric current, its diameter, in from five to ten seconds, became one-third less, and the area of its section about one-half. On continuing the stimulus, the narrowing gradually increased, until the caliber of the tube became from three to six times smaller than it was at first, so that only a single row of blood-corpuscles could pass along it at once; and eventually the vessel was closed and the current of blood arrested.

Thus, with the exception of the largest trunks, the arteries appear to offer every necessary evidence of muscularity. One of their coats has the structure and chemical composition of organic muscle; and, like such muscle, they contract on exposure, on division and mechanical irritation, after death, with a kind of *rigor mortis*, on the application of cold, and under the stimulus of electricity: in all



these contractions they are reduced to a size less than that which their mere elasticity would give them, and from all they are commonly, after a time, again by their elasticity restored to a larger size.

With regard to the *purpose served by the muscular coat of the* arteries, there appears no sufficient reason for supposing that it, in any way, assists in propelling the onward current of blood. It could not do so unless it possessed the property of alternately contracting and relaxing coincidently with the relaxation and contraction of the ventricles; or unless it had a kind of peristaltic or vermicular movement commencing at the heart, and thence propagating itself rapidly along the several arteries; but there is no evidence to show that the arteries ever contract in either of these modes. The most probable office of the muscular coat is that of regulating the quantity of blood to be received by each part, and of adjusting it to the requirements of each, according to various circumstances; but, chiefly and most naturally, according to the activity with which the functions of each part are at different times performed. The amount of function discharged by each organ of the body varies at different times, and the variations often quickly succeed each other, so that, like the brain, for example, during sleep and waking, within the same hour, a part may be now very active and then inactive. In all its active exercise of function, such a part requires a larger supply of blood than is sufficient for it during the times when it is comparatively inactive. It is evident that the heart cannot regulate the supply to each part at different periods, neither could it be regulated by any general and uniform contraction of the arteries; but it may be regulated by the power which the arteries of each part have, in their muscular coat, of contracting so as to diminish, and of passively dilating or yielding so as to permit an increase of the supply of blood, according as the requirements of the part may demand. And thus, while the ventricles of the heart determine the total quantity of blood to be sent onwards at each contraction, and the force of its propulsion, and while the large and merely elastic arteries distribute it and equalize its stream, the smaller arteries with muscular coats add to these two purposes, that of regulating and determining the proportion of the whole quantity of blood which shall be distributed to each part.

The contraction of an artery may also be regarded as fulfilling a natural purpose when, the artery being cut, it first limits and then arrests the escape of blood. It is only because of such contraction that we are free from danger through even very slight wounds; for it is only when the artery is closed that the processes for the more permanent and secure prevention of bleeding are established.

There are occasions in which the whole of the arteries appear to be contracted; such are those of diseases attended with a small hard pulse, but they probably occur only in morbid conditions, and *physiology* appears incapable of explaining them.

ıe normal contraction of arteries is probably excited through the
amentality of the nerve-fibres of the sympathetic system dis-
ted in their walls, and connected through the medium of ganglia
the fibres supplying the organ to which such arteries convey
l.

om what has been said in the preceding pages, it appears that
ffice of the arteries in the circulation is, 1st, the conveyance
distribution of blood to the several parts; 2d, the equalization
e current, and the conversion of the pulsatile, jetting movement
ı to the blood by the ventricles, into the uniform flow; 3d, the
lation of the supply of blood to each part. In explanation of
node in which by the combination of the elastic and muscular
ı of arteries this threefold office is accomplished, we may use,
summary of what has been already said, the words of Mr.
ter, who observes that, "there are three states in which an
y is found, viz. 1st, the natural pervious state; 2d, the
ched; and 3d, the contracted state, which may or may not be
ious. The natural pervious state is that to which the elastic
:r naturally brings a vessel which has been stretched beyond
ntracted within the extent which it held in a state of rest.
stretched is that state produced by the impulse of the blood
onsequence of the contraction of the heart; from which it is
ı brought back to the natural state by the elastic power, per-
assisted by the muscular. The contracted state of an artery
s from the action of the muscular power, and is again restored
ıe natural state by the elastic," (i. vol. iii. p. 159.)

The Pulse.

he jetting movement of the blood, which, as just stated, it is
of the offices of the arteries to change and put an end to, is
ause of *the pulse*, and therefore needs a separate consideration.
have already said that as the blood is not able to pass through
rteries so quickly as it is forced into them by the ventricle,
ccount of the resistance it experiences in the capillaries, a part
ıe force with which the heart impels the blood is exercised upon
valls of the vessels which it distends. The distension of each
y increases both its length and its diameter; but the elonga-
is the most considerable. In their elongation the arteries
ge their form, the straight ones becoming curved, and those
dy curved becoming more so;[1] but they recover their previous

[1] There is, perhaps, an exception to this in the case of the aorta, of which
rve is by some supposed to be diminished when it is elongated; but
; be so, it is because only one end of the arch is immovable; the other
vith the heart, may move forward slightly when the ventricles con-

form as well as their diameter when the ventricular contraction ceases, and their elastic walls recoil. The increase of their curves which accompanies the distension of arteries, and the succeeding recoil may be well seen in the prominent temporal artery of an aged person. The elongation of the artery is in such a case quite manifest.

The dilatation or increase of the diameter of the artery is less evident. In several reptiles it may be seen without aid in the immediate vicinity of the heart (i. vol. iii. p. 216, *note*), and it may be watched with a simple magnifying glass, in the aorta of the tadpole. Its slight amount in smaller arteries, the difficulty of observing them in opaque parts, and the rapidity with which it takes place, are sufficient to account for its being, in Mammalia, imperceptible to the eye. But in these also experiment has made its occurrence probable. Poiseuille (lxii. t. ix. p. 44) laid bare the common carotid of a living horse for the space of about twelve inches, and passed beneath it a tube of metal open at one side, which he afterwards closed by means of a narrower portion, so as to complete the tube; he then stopped the ends of the tube, and filled the interior around the artery with water, by means of a glass tube which was connected with the metallic tube. At every pulsation the water rose 70 millimetres[1] in the glass tube, the diameter of which was 3 millimetres, and fell again the same distance during each interval. The included portion of artery measured in length 180 millimetres, and its capacity equalled 11,440 cubic millimetres; and since at every beat of the heart it underwent an increase of capacity equal to a column of water of 3 millimetres in diameter and 70 millimetres in height, or about 494 cubic millimetres, it follows that it was enlarged about 1-23d of its capacity. It is probable that part of this enlargement was owing to dilatation: and Flourens, in evidence of such dilatation, says he encircled a large artery with a thin elastic metallic ring cleft at one point, and that at the moment of pulsation the cleft part became perceptibly widened.

This dilatation of an artery, and its elongation producing curvature, or increasing its natural curves, are sensible to the finger placed over it, and produce the pulse. The mind cannot distinguish the sensation produced by the dilatation, from that produced by the elongation and curving; that which it perceives most plainly is the curving, or, as it may be called, the locomotion of the artery; the portion that is under the finger slightly shifting its place as it lengthens in pulsation.

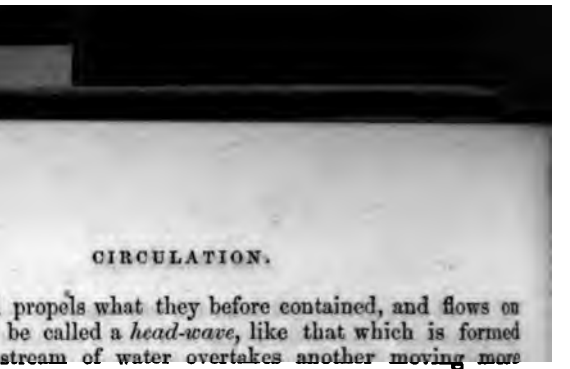
Such, it is generally agreed, is the cause of the pulse felt in any artery; it is produced by the elongation and dilatation of the part under the finger, when it receives its portion of the fresh quantity

[1] A millimetre equals 0.0393708 of an English inch.

f blood just discharged from the left ventricle into the aorta and s branches. But some doubt still exists in reference to the man- er in which the pulse is propagated from one part of the arterial stem to another. According to the theory of the pulse advanced y E. H. Weber (lxvi.), and adopted by Müller, the impulse given o the blood by the heart distends first merely the arteries nearest o the heart. These, by their elasticity, again contract, and thus ause the distension of the next portion of the arterial system, hich, also, in its turn, by contracting, forces the blood into the ext portions, and so on; so that a certain interval of time, although a very short one, elapses before this undulation, resulting from the successive compressions of the blood and the dilatation and contraction of the arteries, reaches the most distant parts of the system. In this view, the arterial pulse is regarded as the effect of an oscillation or undulation, produced first by the pressure on the blood in the aorta by the contracting left ventricle, and thence propagated along the walls of the arteries, and along the blood itself.

But against this theory a very forcible objection presents itself in the fact recently pointed out by Mr. F. H. Colt (lxi. vol. xxxvi. p. 456), viz., that the pulse is perceived in every part of the arterial system previous to the occurrence of the second sound of the heart, that is, previous to the closure of the aortic valves. Now, if the pulse were the effect of a wave propagated by the alternate dilatation and contraction of successive portions of the arterial tube, it ought in all the arteries except those "nearest to the heart" to follow, or coincide with, but could never precede, the second sound of the heart; for the first effect of the elastic recoil of the arteries first dilated (which recoil, on Weber's theory, causes the dilatation and pulse in the arteries following those nearest to the heart), is the closure of the aortic valves, and their closure produces the second sound. It appears impossible to reconcile Weber's theory with this fact; the contraction of the arteries nearest to the heart, which he supposes to produce the pulse in those further on, certainly produces, by closing the valves, the second sound of the heart; yet, this sound always, or nearly always, follows the pulse even in the most distant arteries in which it can be felt. It seems certain, therefore, that the contraction of the arteries nearest the heart does not take place till after the pulse in the more distant ones.

The theory proposed by Mr. Colt, which seems to reconcile all the facts of the case, and especially those two which appear most opposed, namely, that the pulse always precedes the second sound of the heart, and yet is later in the arteries far from the heart than in those near it, may be thus stated: It supposes that the blood which is impelled onwards by the left ventricle does not so impart its pressure to what the arteries already contain as to dilate the whole arterial system at once; but that, as it enters the arteries,



it displaces and propels what they before contained, and flows on with what may be called a *head-wave*, like that which is formed when a rapid stream of water overtakes another moving more slowly. The slower stream offers resistance to the more rapid one, till their velocities are equalized: and, because of such resistance, some of the force of the more rapid stream of blood just expelled from the ventricle, is diverted laterally, and with the rising of the wave the arteries nearest the heart are dilated and elongated. They do not at once recoil, but continue to be distended so long as blood is entering them from the ventricle. The wave at the head of the more rapid stream of blood runs on, propelled and maintained in its velocity by the continuous contraction of the ventricle: and it thus dilates in succession every portion of the arterial system, and produces the pulse in all. The rate of its movement, which represents also the velocity of the blood in the arteries during the ventricular contraction, may be estimated by the interval between the pulses near and far from the heart. At length, the whole arterial system (wherein a pulse can be felt) is dilated; and at this time, when the wave we have supposed has reached all the smaller arteries, the entire system may be said to be simultaneously dilated; then it begins to contract, and the contractions of its several parts ensue in the same succession as the dilatations commencing at the heart. The contraction of the first portion produces the closure of the valves and the second sound of the heart; and both it and the progressive contractions of all the more distant parts maintain, as already said, that pressure on the blood during the inaction of the ventricle by which the stream of the arterial blood is sustained between the jets, and is finely equalized by the time it reaches the capillaries.

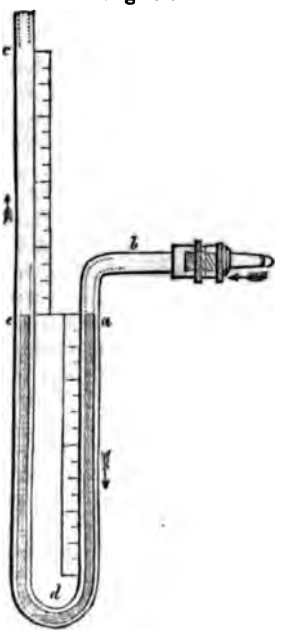
It may seem an objection to this theory that it would probably require a larger quantity of blood to dilate all the arteries than can be discharged by the ventricle at each contraction. But the quantity necessary for such a purpose is less than might be supposed. Injections of the arteries prove that, including all down to those of about one-eighth of a line in diameter, they do not contain, on an average, more than one and a half pints of fluid even when distended. There can be no doubt, therefore, that the three ounces which the ventricle is supposed to discharge at each contraction, being added to that which already fills the arteries, would be sufficient to distend them all.

Force of the Blood in the Arteries.

The force with which the ventricles act in their contraction, and the reasons for believing it sufficient for the circulation of the blood, have been already mentioned. Both calculation and experiment have proved that very little of this force is consumed in the arteries.

Dr. Thomas Young (xliii. vol. xcix.) calculated that the loss of force in overcoming friction and other hindrances in the arteries would be so slight, that if one tube were introduced into the aorta, and another into any other artery, even into one as fine as a hair, the blood would rise in the tube from the small vessel to within two inches of the height to which it would rise from the large vessel. The correctness of the calculation is established by the experiments of Poiseuille (lxii. t. viii. p. 272), who invented an instrument named a hæmadynamometer, for estimating the statical pressure exercised by the blood upon the walls of the arteries. It consists of a long glass tube bent so as to have a short horizontal portion (Fig. 22, *a*), a branch *b* descending at right angles from it, and a long ascending branch *d, e, c*. Mercury poured into the ascending and descending portions will necessarily have the same level in both branches, and in a perpendicular position the height of its column must be the same in both. If, now, the blood is made to flow from an artery, through the horizontal portion of the tube (which should contain a solution of carbonate of potash to prevent coagulation) into the descending branch, it will exert on the mercury a pressure equal to the force by which it is moved in the arteries, and the mercury will, in consequence, descend in this branch, and ascend in the other. The depth to which it sinks in the one branch, added to the height to which it rises in the other, will give the whole height of the column of mercury which balances the pressure exerted by the blood; the weight of the blood which takes the place of the mercury in the descending branch, and which is more than ten times less than the same quantity of quicksilver, being subtracted. Poiseuille thus calculated the force with which the blood moves in an artery, accord-

Fig. 22.



Hæmadynamometer of Poiseuille. A bent glass tube, filled with mercury in the lower part, *a d e*. The horizontal part, *b*, is provided with a brass head, which fits in the artery. A small quantity of a solution of the carbonate of soda is interposed between the mercury and the blood, to prevent its coagulation. When the blood presses on the fluid in the horizontal limb, the rise of the mercury towards *e*, measured from the level to which it has fallen towards *a*, gives the pressure under which the blood moves.

ing to the laws of hydrostatics, from the diameter of the artery, and the height of the column of quicksilver; that is to say, from the weight of a column of mercury whose base is a circle of the same diameter as the artery, and whose height is equal to the difference in the levels of the mercury in the two branches of the instrument. He found the blood's pressure equal in all the arteries examined; difference in size, and distance from the heart, being unattended by any corresponding difference of force in the circulation. The height of the column of mercury displaced by the blood was the same in all the arteries of the same animal.

From the mean result of several observations on horses and dogs, he calculated that the force with which the blood is moved in any large artery is capable of supporting a column of mercury six inches and one and a half lines in height, or a column of water seven feet one line in height. With these results the more recent observations of Valentin (iv. p. 441), Spengler (lxxx. 1844), and Ludwig (lxxx. 1847, p. 242), closely accord. Poiseuille's experiments having thus shown to him that the force of the blood's motion is the same in the most different arteries, he concluded that to measure the amount of the blood's pressure in any artery of which the caliber is known, it is necessary merely to multiply the area of a transverse section of the vessel by the height of the column of mercury which is already known to be supported by the force of the blood in any part of the arterial system. The weight of a column of mercury of the dimensions thus found will represent the pressure exerted by the column of blood. And assuming that the mean of the greatest and least height of the column of mercury found by experiments on different animals to be supported by the force of the blood in them, is equivalent to the height of the column which the force of the blood in the human aorta would support, he calculated that about 4 lbs. 4 oz. avoirdupois will indicate the static force with which the blood is impelled into the human aorta. By the same calculation, he estimates the force of the circulation in the aorta of the mare to be about 11 lbs. 9 oz. avoirdupois: and that in the radial artery at the human wrist only 4 drs. We have already seen that the muscular force of the right ventricle is equal to only half that of the left, consequently, if Poiseuille's estimate of the latter is correct, the force with which the blood is propelled into the lungs will only be equal to 2 lbs. 2 oz. avoirdupois.

The amounts above stated indicate the pressure exerted by the blood at the several parts of the arterial system at the time of the ventricular contraction. During the dilatation this pressure is somewhat diminished. Hales observed that the column of blood in the tube inserted into an artery falls an inch or rather more after each pulse; Ludwig (lxxx. 1847, p. 242) has observed the same,

ded it more minutely. The pressure is also influenced by
us circumstances which affect the action of the heart; the
on or increase of the pressure being proportioned to the
r stronger action of this organ. Valentin observed that,
sing the amount of blood by the injection of a fresh
into it, the pressure in the vessels was also increased,
ontrary effect ensued on diminishing the quantity of blood.
uille, Ludwig, and others have confirmed what Haller and
e observed, namely, that the strength of the blood's im-
the arteries is increased during expiration; in which act
t is contracted, and the large vessels in consequence com-

The column of mercury in the hæmadynamometer rises
at at each expiration, and falls during inspiration. The
f the rise and fall of the mercury observed by Poiseuille
same in arteries the distance of which from the heart was
t; and in ordinary tranquil respiration amounted to from
ten lines. The decrease of the arterial blood's impulse in
ion is in some persons so great, that the pulse at the radial
becomes imperceptible when inspiration is long continued
breath held; its increase in expiration is well shown in the
d pain and throbbing of an inflamed part during coughing,
the frequency of rupture in diseased arteries during violent
ory efforts. These things will be again referred to in speak-
the movement of the venous blood.

THE CAPILLARIES.

ll organic textures the transmission of the blood from the
branches of the arteries to the minute veins is effected
h a network of microscopic vessels, in the meshes of which
per substance of the tissue lies. (Fig. 23.) This may be
all minutely injected preparations; and, during life, by the
the microscope, in any transparent parts, such as the web of
g's foot, the lungs, tongue, and urinary bladder of the frog,
il or external branchiæ of the tadpole, the incubated egg,
fishes, the wings of the bat, and the mesentery of all Verte-
and even in some opaque textures of the larva of the sala-
r by means of a simple microscope. The ramifications of
nute arteries form repeated anastomoses with each other, and
f the capillaries, which, by their anastomoses, compose a con-
s and uniform network, from which the venous radicles, on
ier hand, take their rise. The reticulated vessels, connecting
teries and veins, are called capillary, on account of their
size; and intermediate vessels, on account of their position.
oint at which the arteries terminate and the minute veins

Fig. 23.

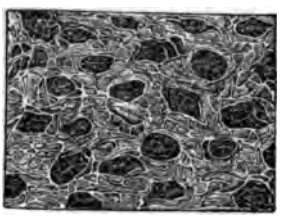
Bloodvessels of an intestinal villus, representing the arrangement of capillaries between the ultimate venous and arterial branches; 1, 1, the arteries; 2, the vein.

commence cannot be exactly defined, for the transition is gradual; but the intermediate network has, nevertheless, this peculiarity, that the small vessels which compose it maintain the same diameter throughout; they do not diminish in diameter in one direction, like arteries and veins; and the meshes of the network that they compose are more uniform in shape and size than are those formed by the anastomoses of the minute arteries and veins.

The *diameter* of the capillary vessels varies somewhat in the different textures of the body, the most common size being about 1-3000th of an inch. Among the smallest may be mentioned those of the brain, and of the mucous membrane of the intestines; among the largest, those of the skin, and especially of the medulla of bones.

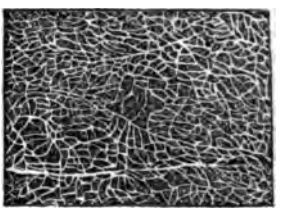
The *form of the capillary network* presents considerable variety in the different textures of the body; the varieties consisting principally of modifications of two chief kinds of mesh, the rounded and the elongated. That kind in which the meshes or interspaces have a roundish form is the most common, and prevails in those parts in which the capillary network is most dense, such as the lungs, most glands, and mucous membranes, and the cutis. (Fig. 24.) The

Fig. 24.



Distribution of capillaries around follicles of mucous membrane.

Fig. 25.



Capillary network of nervous centres.

meshes of this kind of network are not quite circular, but more or less angular, sometimes presenting a nearly regular quadrangular

al form, but being more frequently irregular. The capil-
rk with elongated meshes is observed in parts in which the
s arranged among bundles of fine tubes or fibres, as in
id nerves. (Fig. 25.) In such parts the meshes usually
orm of a parallelogram, the short sides of which may be
s to eight or ten times less than the long ones; the long
ays corresponding to the axis of the fibre or tube, by
is placed. The appearance both of the rounded and
mesh is much varied according as the vessels com-
have a straight or tortuous
ometimes the capillaries have
arrangement, a single ca-
rojecting from the common
into some prominent organ,
rning after forming one or
ops, as in the papillæ of the
and skin. (Fig. 26.) What-
the form of the capillary net-
any tissue or organ, it is, as
found to prevail in the cor-
ng parts of all animals.

Fig. 26.

Capillary network of fungiform papilla of the tongue.

number of the capillaries and the *size of the meshes* in differ-
s determine in general the degree of *vascularity* of those
The parts in which the network of capillaries is closest,
in which the meshes or interspaces are the smallest, are the
nd the choroid membrane of the eye. In the iris and
ody, the interspaces are somewhat wider, yet very small.
human liver, the interspaces are of the same size, or even
than the capillary vessels themselves. In the human lung
smaller than the vessels. In the human kidney, and in
ney of the dog, the diameter of the injected capillaries,
d with that of the interspaces, is in the proportion of one
or of one to three. The brain receives a very large quan-
blood; but the capillaries in which the blood is distributed
its substance are very minute, and less numerous than in
her parts; their diameter, according to E. H. Weber, com-
ith the long diameter of the meshes, being in the propor-
ne to eight or ten; compared with the transverse diameter,
proportion of one to four or six. In the mucous mem-
—for example, in the conjunctiva—and in the cutis vera,
llary vessels are much larger than in the brain, and the
ces narrower—namely, not more than three or four times
an the vessels. In the periosteum, the meshes are much
In the cellular coat of arteries, the width of the meshes is
s that of the vessels (Henle).
y be held as a general rule that the more active the func-

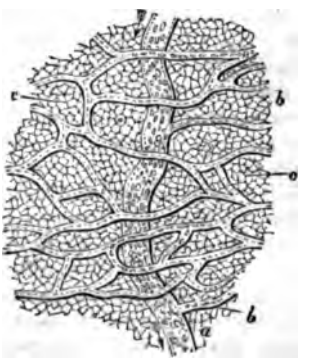
tions of an organ are the more vascular it is, that is, the closer is its capillary network and the larger its supply of blood. Hence the narrowness of the interspaces in all glandular organs, in mucous membranes, and in growing parts; their much greater width in bones, ligaments, and other very tough and comparatively inactive tissues; and the complete absence of vessels in cartilages, the dense tendons of adults, and such parts, in which, probably, very little organic change occurs after they are once formed. But the general rule must be modified by the consideration that some organs, such as the brain, though they have small and not closely arranged capillaries, may receive large supplies of blood by reason of its more rapid movement. When an organ has large arterial trunks and a comparatively small supply of capillaries, the movement of the blood through it will be so quick, that it may in a given time receive as much fresh blood as a more vascular part with smaller trunks, though at any given instant the less vascular part will have in it a smaller quantity of blood.

Microscopic observations and minute injections have shown that the capillary vessels are merely the fine tubes which form the medium of transition from arteries to veins, and that no other kind of vessel arises from them; that the minute arteries have no other mode of termination than the communication with the veins by means of the capillaries; in a word, that there are no exhalant or other vessels terminating by open extremities. The hypothesis of the existence of such vessels is alike unnecessary to the explanation of secretion, growth, nutrition, and all the other functions of a part. All that these functions require of the vessels is, that, for each tissue, the blood should be brought so near to the active elements of the tissue, that some of its fluid part may be absorbed or imbibed by them. And the distance through which such imbibition is effected is not always small; in the brain, for example, those portions of its substance which lie in the middle of the wide meshes of the capillary network must be nourished by imbibing fluid through the spaces between them and the nearest vessels; so also in bone, where the vessels are yet wider apart. But the instances in which such imbibition is effected through the greatest distance are in what are called non-vascular tissues, which receive no bloodvessels into their own substance, and are nourished by the fluid absorbed from the vessels of the adjacent vascular parts; as the cornea from the vessels of the conjunctiva, the lens from those of the posterior layer of its capsule, and the articular cartilage from the vessels of the subjacent bone. The difference of nutrition in vascular and non-vascular tissues is only one of degree; in all parts alike the elementary structures are outside the vessels, and obtain new materials from the blood by imbibition; but the imbi-

as to be accomplished through a greater distance in the
n in the more vascular parts.
structure of the capillaries offers little hindrance to such
on. Their walls are composed of exceedingly fine, trans-
and apparently homogeneous membrane, in which are im-
here and there, minute oval corpuscles, probably the per-
nuclei of the cells from which the vessels were originally
Only in the largest capillaries are there traces of an epi-
lining like that of the arteries, or of filaments, like rudi-
of a circularly fibrous coat.

e Circulation in the Capillaries, as seen in any transparent
a living adult animal by means of the microscope (Fig. 27),
od flows with a constant equable motion. In very young
s the motion, though continuous, is accelerated at intervals,
onding to the pulse in the larger arteries, and a similar mo-
the blood is also seen in the capillaries of adult animals
hey are feeble: if their exhaustion is so great that the power
heart is still more diminished, the red corpuscles are observed
e merely the periodic motion, and to remain stationary in the
ls; while, if the debility of the animal is extreme, they even
somewhat after each impulse, apparently because of the
ity of the capillaries and the tissues round them. These
ations may be added to those already (p. 89) advanced, to
that, even in the state of debility, the action of the is sufficient to impel the through the capillary ves-
Moreover, Dr. Marshall (xciv. 1843) having placed ectoral fin of an eel in the of the microscope, and com-d it by the weight of a heavy observed that the movement blood in the capillaries be-obviously pulsatory, the pul-s being synchronous with the ctions of the ventricle. This of the heart to propel the through a second set of capil-affords an explanation of the circulation, and of the more lt problem, the circulation h the acardiac fœtus. The pulsatory motion of the blood in illaries cannot be attributed to an action in these vessels;

Fig. 27.



Capillaries in the web of the frog's foot magnified.

for, when the animal is tranquil, they present not the slightest change in their diameter.

It is in the capillaries that the chief resistance is offered to the progress of the blood; for in them the friction of the blood is greatly increased by the enormous multiplication of the surfaces with which it is brought in contact. The velocity of the blood is, also, in them reduced to its minimum, because of the widening of the stream. If, as Professor Müller says, the sectional area of all the branches of a vessel united were always the same as that of the vessel from which they arise, and if the aggregate sectional area of the capillary vessels were equal to that of the aorta, the mean rapidity of the blood's motion in the capillaries would be the same as in the aorta and largest arteries; and, if a similar correspondence of capacity existed in the veins and arteries, there would be an equal correspondence in the rapidity of the circulation in them. It is quite true that the force with which the blood is propelled in the arteries, as shown by the quantity of blood which escapes from them in a certain space of time, is much greater than that with which it moves in the veins; but this force has to overcome all the resistance offered in the arterial and capillary system—the heart itself, indeed, must overcome this resistance; so that the excess of the force of the blood's motion in the arteries is expended in overcoming this resistance, and the rapidity of the circulation in the arteries, even from the commencement of the aorta, would be the same as in the veins and capillaries, if the aggregate capacity of each of the three systems of vessels were the same.

But since the aggregate sectional area of the branches is greater than that of the trunk from which they arise, the rapidity of the blood's motion will necessarily be greater in the trunk, and will diminish in proportion as the aggregate capacity of the vessels increases during their ramification: in the same manner as, other things being equal, the velocity of a stream diminishes as it widens.

The observations of Hales (lxvii. vol. ii.), E. H. Weber (lxxx. 1838, p. 450) and Valentin (iv. vol. i. p. 468) agree very closely as to the rate of the blood in the capillaries of the frog: and the mean of their estimates gives the velocity of the systemic capillary circulation at about one inch per minute. Through the pulmonic capillaries, the rate of motion according to Hales, is about five times that through the systemic ones. The velocity in the capillaries of warm-blooded animals is greater, but has not yet been accurately estimated. If it be assumed to be three times as great as in the frog, still the estimate may seem too low, and inconsistent with the facts which show that the whole circulation is accomplished in about a minute. But the whole length of capillary vessels, through which any given portion of blood has to pass, pro-

y does not exceed 1-30th of an inch; and, therefore, the time ired for each quantity of blood to traverse its own appointed ion of the general capillary system will not be more than two nds: while in the pulmonic capillary system the length of e required will be even much less than this.

he estimates given above are drawn from observations of the rements of the red blood-corpuscles, which move in the centre the stream. At the circumference of the stream, in contact h the walls of the vessels, and adhering to them, there is a er of liquor sanguinis, which appears to be motionless. The stence of this *still layer*, as it is termed, is inferred both from general fact that such an one exists in all fine tubes traversed fluid, and from what can be seen in watching the movements of blood-corpuscles. The red corpuscles occupy the middle of stream, and move with comparative rapidity; the colorless mph-corpuscles run much more slowly by the walls of the vessels; ile next to the wall there is often a transparent space in which fluid appears to be at rest; for if any of the corpuscles happen be forced within it, they move more slowly than before, rolling ily along the side of the vessel, and often adhering to its wall. rt of this slow movement of the pale corpuscles, and their occa- nal stoppage may be due, as E. H. Weber has suggested, to eir having a natural tendency to adhere to the walls of the ves- ls. Sometimes, indeed, when the motion of the blood is not ong, many of the white corpuscles collect in a capillary vessel, d for a time entirely prevent the passage of the red corpuscles. at there is no doubt such a still layer of liquor sanguinis exists xt the walls of the vessels, and it is between it and the tissues ound the vessels that those interchanges of particles take place ich ensue in nutrition, secretion, and absorption by the blood- ssels; interchanges which are probably facilitated by the tran- illity of the fluids between which they are effected.

There is no reason for supposing that either the pale or red cor- scles ever remain permanently fixed to the wall of the vessels, d become united with them, or that they pass through the walls enter into the structure of the tissues. Their office appears to fulfilled exclusively within the vessels.

The reasons have been already stated for holding that the power the heart is sufficient to propel the blood through the capillary stem (see p. 89). There is, therefore, no need of an hypothe- of any action of the capillaries for the regular propulsion of the od through them; nor is it probable that they have such an ce. There is some evidence for supposing that, under certain cumstances, the capillaries can exercise an influence on their ntents; but, as it will appear, the phenomena on which this sup- sition is founded, are as well explained by referring them to the

action of the small arteries, or to the relation which exists between the tissues outside, and the blood within, the capillaries.

Thus, the capillaries contract on the application of cold: but this may be due not to any contraction similar to that of muscular tissue, but to the elasticity of the capillaries, and the surrounding tissues which close in, when, by the contraction of the small arteries (which as already stated, can be made to contract by cold), the flow of blood into the capillaries is diminished.

The apparent contraction of the capillaries on the application of certain irritating substances, and during fear, and their dilatation in blushing, may be similarly referred to either their own action, or that of the small arteries.

When the access of oxygen to the lungs is prevented, the circulation through the pulmonic capillaries is gradually retarded, the blood-corpuscles cluster together, and their movement is eventually almost arrested, even while the action of the heart continues. In inflammation, also, the capillaries of an inflamed part are enlarged and distended with blood, which either moves very slowly, or is completely at rest. In both these cases the change may be due to some influence exercised by the capillaries on the blood; but, in both also, it may be that an alteration in the blood increases the adhesion of its particles to one another, and to the walls of the capillaries, to an amount which the propelling action of the heart is not able to overcome.

The temporary increase in the size of the capillaries, and in the quantity of blood moving through them in any part, during an unusually active discharge of its functions, has been cited as evidence of their exercising some power to determine the amount of blood that shall traverse them. Instances of such enlargement are seen in the turgescence of an actively secreting or quickly growing part. But the control here displayed may be exercised, not by the capillaries, but by that relation, whatever be its nature, which exists between every tissue and the blood, and by which the condition of the tissue determines the quantity of blood to be supplied to it; as in the rudimental state, the condition of each organ or tissue determines the first formation and supply of blood to it.

It thus appears that the capillaries are capable of contraction and dilatation, but we cannot say whether these changes of size are effected by their proper and primary agency, or are the results of their being merely extensile and elastic, and thereby capable of adapting themselves to changes in the quantity of blood impelled into them. We seem to have at present no means of determining this question.

The Veins.

In *structure*, the coats of veins bear a general resemblance to those of arteries. They possess, however, no complete elastic coat; what

elastic tissue they have is interwoven in their fibro-cellular tissue, which, being itself also extensile and elastic, enables them to recover from the temporary extensions to which they are liable. That part of their walls, also, which corresponds with the muscular coat of the arteries is composed of fibres resembling those of fibro-cellular tissue, rather than of organic muscle. It is probable, however, that this fibro-cellular tissue is contractile like that of the skin, and that through it the veins possess some power of independently contracting on their contents. (See exc. July, 1850, p. 241.) To the great trunks of the veins, where they are near the auricles, more of this power is given by a circular layer of striated muscular fibres like those of the auricles, which takes the place of the contractile fibro-cellular tissue, and the action of which has been already referred to (p. 73). But, in the rest of the veins, the contractile power is probably weak and of slow action; sufficient, however, to enable them to adapt themselves to the size required when they receive less than their average supply of blood through the arteries; while to the usual, or more than the usual, supply they are adapted by the extensile and elastic property of all their coats.

The chief influence that the veins have in the circulation is effected with the help of the *valves*, which are placed in all veins that are subject to local pressure from the muscles between or near which they run. The general construction of these valves is similar to that of the semilunar valves of the aorta and pulmonary artery, already described (p. 75); but their free margins are turned in the opposite direction, *i. e.*, *towards* the heart, so as to stop any movement of blood backwards in the veins. They are commonly placed in pairs, at various distances in different veins, but almost uniformly in each. In the smaller veins, single valves are often met with: and three or four are sometimes placed together, or near one another, in the largest veins, such as the subclavian, and at their junction with the jugular veins. The valves are semilunar: the unattached edge being in some examples concave, in others straight. They are composed of inextensile fibrous tissue, and are covered with epithelium like that lining the veins. During the period of their inaction, when the venous blood is flowing in its proper direction, they lie by the sides of the veins; but when in action, they close together like the valves of the arteries, and offer a complete barrier to any backward movement of the blood.

The principal obstacle to the circulation is already overcome when the blood has traversed the capillaries; and the force of the heart which is not yet consumed, is sufficient to complete its passage through the veins, in which the obstructions to its movement are very slight. For the formidable obstacle supposed to be presented by the gravitation of the blood has no real existence, since the pressure exercised by the column of blood in the arteries will

be always sufficient to support a column of venous blood of the same height as itself: the two columns mutually balancing each other. Indeed, so long as both arteries and veins contain continuous columns of blood, the force of gravitation, whatever be the position of the body, can have no power to move or resist the motion of any part of the blood in any direction: as if one had a circular tube full of fluid at every part, the fluid might be made to circulate with equal facility in either direction, or in any position of the tube. The lowest bloodvessels have, of course, to bear the greatest amount of pressure; the pressure on each part being directly proportionate to the height of the column of blood above it: hence their liability to distension. But this pressure bears equally on both arteries and veins, and cannot either move, or resist the motion of, the fluid they contain, so long as the columns of fluid are in both of equal height, and continuous. Their condition may in this respect be compared with that of a double bent tube, full of fluid, held vertically; whatever be the height and gravitation of the columns of fluid, neither of them can move of its own weight, each being supported by the other; yet the least pressure on the top of either column will lift up the other; so, when the body is erect, the least pressure on the column of arterial blood may lift up the venous blood, and, were it not for the valves, the least pressure on the venous might lift up the arterial column.

In experiments to determine what proportion of the force of the left ventricle remains to propel the blood in the veins, Valentin found that the pressure of the blood in the jugular vein of a dog, as estimated by the hæmadynamometer, did not amount to more than 1-11th or 1-12th of that in the carotid artery of the same animal; and this estimate is confirmed, in the instances of several other arteries and their corresponding veins, by Mogk (xxxiii. 1845, p. 33). In the upper part of the inferior vena cava, Valentin could scarcely detect the existence of any pressure, nearly the whole force received from the heart having been, apparently, consumed during the passage of the blood through the capillaries (iv. p. 477). But, slight as this remanent force might be (and the experiment in which it was estimated would reduce the force of the heart below its natural standard), it would be enough to complete the circulation of the blood; for, as already stated (p. 86), the spontaneous dilatation of the auricles and ventricles, though it may not be forcible enough to assist the movement of blood into them, is adapted to offer to that movement no obstacle.

Some *assistance* is given to the venous circulation by the *respiratory movements* of the chest; and some occasionally, but very effectually and timely, by the *actions of the muscles*, capable of pressing on such veins as have valves.

The *effect of muscular pressure* on such veins may be thus ex-

plained. When pressure is applied to any part of a vein, and the current of blood in it is obstructed, the portion behind the seat of pressure becomes swollen, and distended as far back as to the next pair of valves. These, acting like the arterial valves, and being like them inextensile, both in themselves and at their margins of attachment, do not follow the vein in its distension, but are drawn out towards the axis of the canal. Then, if the pressure continues on the vein, the compressed blood, tending to move equally in all directions, presses the valves down into contact at their free edges, and they close the vein and prevent regurgitation of the blood. Thus, whatever force is exercised by the pressure of the muscles on the veins is distributed partly in pressing the blood onwards in the proper course of the circulation, and partly in pressing it backwards and closing the valves behind.

The circulation might lose as much as it gains by such compression of the veins, if it were not for the numerous anastomoses by which they communicate with one another; for through these, the closing up of the venous channel by the backward pressure is prevented from being any serious hindrance to the circulation, since the blood, of which the onward course is arrested by the closed valves, can at once pass through some anastomosing channel, and proceed on its way by another vein. Thus, therefore, the effect of muscular pressure upon veins that have valves is turned almost entirely to the advantage of the circulation; the pressure of the blood onwards is all advantageous, and the pressure of the blood backwards is prevented from being a hindrance by the closure of the valves and the anastomoses of the veins.

The effects of such muscular pressure are well shown by the acceleration of the stream of blood, when, in venesection, the muscles of the forearm are put in action, and by the general acceleration of the circulation during active exercise; and the numerous movements which are continually taking place in the body while awake, though their single effects may be less striking, must be an important auxiliary to the venous circulation. Yet they are not essential; for the venous circulation continues unimpaired in parts at rest, in paralyzed limbs, and in parts in which the veins are not subject to any muscular pressure.

The *respiratory movements* of the chest also assist the circulation of the blood in the systemic veins: at least, the more forcible respiratory movements do; the ordinary ones are too weak to produce any considerable effect. The effect of expiration in increasing the pressure of the blood in the arteries, has been already mentioned (page 103), and is minutely illustrated by the experiments of Ludwig (lxxx. 1847, p. 242). It acts as the pressure of contracting muscles does upon the veins, and is advantageous to the movement of arterial blood, while the aortic valves are closed, be-

cause, during this time, the backward pressure cannot wholly neutralize the benefit of the pressure forwards. The increased pressure on the blood in the arteries, during expiration, is also propagated through the capillaries to some of the veins; for Magendie has shown that the stream of venous blood from the lower end of a divided vein becomes stronger during each expiration.

But on the whole, little advantage is derived to the circulation from the movements of expiration, since the same pressure which drives on the arterial blood with increased force must, in some degree, retard the blood in the veins, and obstruct its passage to the heart. The effect of such retardations is shown in the swelling up of the veins of the head and neck, and the lividity of the face, during coughing, straining, and similar violent expiratory efforts. The effects shown in these instances are due, both to some regurgitation of blood in the great veins, and to the accumulation of blood in the veins of the head and face, which are constantly more and more filled by the influx from the arteries, and are not able to empty themselves into the vena cava superior. The regurgitation, however, is stopped or much diminished by the valves at the junction of the jugular and subclavian veins, by which, also, the disadvantageous effects of the forced expirations are limited.

The act of inspiration is favorable to the venous circulation, and its effect is not quite counterbalanced by its tending to draw the arterial as well as the venous blood towards the cavity of the chest. When the chest is enlarged in inspiration, the additional space within it is filled, chiefly by the fresh quantity of air which passes through the trachea and bronchial passages to the vesicular structure of the lungs. But the blood, being like the air, subject to the atmospheric pressure, some of it, also, is at the same time pressed towards the expanding cavity of the chest, and therein towards the heart. The effect of this in the arterial current is hindered by the aortic valves, while they are closed; and is less than it is on the venous current, in the same proportion as the orifice of the aorta is less than the united orifices of the two venæ cavæ.

Sir David Barry was the first who showed plainly this effect of inspiration on the venous circulation, and mentions the following experiment in proof of it. He introduced one end of a bent glass tube into the jugular vein of an animal, the vein being tied above the point where the tube was inserted; the inferior end of the tube was immersed in some colored fluid. He then observed that at the time of each inspiration the fluid ascended in the tube, while, during expiration, it either remained stationary, or even sank. Poiseuille confirmed the truth of this observation in a more accurate manner, by means of his hæmadynamometer. And a like confirmation has been more recently furnished by Valentin (iv. p. 478), and in minute details by Ludwig (lxxx. 1847, p. 242).

of inspiration on the veins is observable only in the
r the thorax. Poiseuille could not detect it by means
nent in veins more distant from the heart—for exam-
ns of the extremities. And its beneficial effect would
l were it not for the valves; for he found, when he re-
Barry's experiment, and passed the tube so far along
t it went beyond the valves nearest to the heart, as
ras forced back into the tube in every expiration as
through it in every inspiration.
ole, therefore, the respiratory movements of the chest
eous to the systemic circulation; on the pulmonary
ey appear to produce no effect. The additional force
tion gives to the arterial current is not counterbalanced
lation of the venous current, because the valves of the
, limit the regurgitation from the chest; and though
hind or above these valves is retarded while they are
goes on with accumulated force as soon as they are
On the other hand, the retardation of the arterial
acts of inspiration is less than the acceleration of the
l, because the orifice of the aorta is less than that of
rae.
rbance which hurried respiration and struggling pro-
movement of the venous blood, makes it exceedingly
letermine the average force or velocity of the venous
e *velocity* of the blood is greater in the veins than in
ies, but less than in the arteries; and to this are
relative capacities of the arterial and venous systems;
veins must return to the heart all the blood that they
it, in a given time, through the arteries, their larger
portionally greater number must compensate for the
ment of the blood through them. If an accurate esti-
proportionate areas of arteries and the veins corre-
them could be made, we might, from the velocity of
current, calculate that of the venous. Perhaps a fair
on to such an estimate is, that the capacity of the
at three times as great as that of the arterial system;
velocity of the blood's motion is about one-third less
r than in the latter. And this is not a slow move-
f we stop the circulation at the beginning of any super-
and empty the upper part of the vein, immediately
ng the finger the blood will move along the vein faster
can follow it. The rate at which the blood moves in
adually increases the nearer it approaches the heart,
onal area of the venous trunks, compared with that of
s opening into them, becomes gradually less as the
ace towards the heart.

Having now considered the share which each of the circulatory organs has in the propulsion and direction of the blood, we may speak of their combined effects, especially in regard to the velocity with which the movement of the blood through the whole round of the circulation is accomplished. As Müller says, the rate of the blood's motion in the vessels must not be judged of by the rapidity with which it flows from a vessel when divided. In the latter case, the rate of motion is the result of the entire pressure to which the whole mass of blood is subjected in the vascular system, and which at the point of the incision in the vessel meets with no resistance. In the closed vessels, on the contrary, no portion of blood can be moved forwards but by impelling on the whole mass, and by overcoming the resistance arising from friction in the smaller vessels.

From the rate at which the blood escapes from opened vessels, we could only judge, in general, that its velocity is, as already said, greater in arteries than in veins, and in both than in the capillaries. More satisfactory data for the estimates are afforded by the results of experiments to ascertain the rapidity with which poisons introduced into the blood are transmitted from one part of the vascular system to another. From eighteen such experiments on horses, Hering deduced that the time required for the passage of a solution of ferrocyanide of potassium, mixed with the blood, from one jugular vein (through the right side of the heart, the pulmonary circulation, the left cavities of the heart, and the general circulation) to the jugular vein of the opposite side, varies from twenty to thirty seconds. The same substance was transmitted from the jugular vein to the great saphena in twenty seconds; from the jugular vein to the masseteric artery in between fifteen and thirty seconds, to the facial artery in one experiment in between ten and fifteen seconds, in another experiment in between twenty and twenty-five seconds: in its transit from the jugular vein to the metatarsal artery it occupied between twenty and thirty seconds, and in one instance more than forty seconds. The result was nearly the same whatever was the rate of the heart's action.

Poiseuille's observations (xxxi. 1843) accord completely with the above; and show, moreover, that when the ferrocyanide is injected into the blood with other substances, such as acetate of ammonia, or nitrate of potash (solutions of which, as other experiments have shown, pass quickly through capillary tubes), the passage from one jugular vein to the other is effected in from eighteen to twenty-four seconds; while, if instead of these, alcohol is added, the passage is not completed until from forty to forty-five seconds after injection. Still greater rapidity of transit has been observed by Mr. J. Blake (xciv. Oct. 1841), who found that nitrate of ba-

ryta injected into the jugular vein of a horse could be detected in blood drawn from the carotid artery of the opposite side in from fifteen to twenty seconds after the injection. In sixteen seconds a solution of nitrate of potash, injected into the jugular vein of a horse, caused complete arrest of the heart's action, by entering and diffusing itself through the coronary arteries. In a dog, the poisonous effects of strychnia on the nervous system were manifested in twelve seconds after injection into the jugular vein; in a fowl, in six and a half seconds, and in a rabbit, in four and a half seconds.

In all these experiments, it is assumed that the substance injected moves with the blood, and at the same rate as it, and does not move from one part of the organs of circulation to another by diffusing itself through the blood or tissues more quickly than the blood moves. The assumption is so probable that it may be considered nearly certain that the times above mentioned, as occupied in the passage of the injected substances, are those in which the portion of blood into which each was injected was carried from one part to another of the vascular system. It would, therefore, appear that a portion of blood can traverse the entire course of the circulation, in the horse, in half a minute; of course, it would require longer to traverse the vessels of the most distant part of the extremities than to go through those of the neck; but taking an average length of vessels to be traversed, and assuming, as we may, that the movement of blood in the human subject is not slower than in the horse, it may be concluded that one minute, which is the estimate usually adopted of the average time in which the blood completes its entire circuit in man, is rather above than below the actual rate.

Another mode of estimating the general velocity of the circulating blood is by calculating it from the quantity of blood supposed to be contained in the body, and from the quantity which can pass through the heart in each of its actions. But the conclusions arrived at by this method are less satisfactory. For the estimates both of the total quantity of blood, and of the capacity of the cavities of the heart, are as yet only approximated to the truth. Still, the most recent and careful of the estimates thus made accord with those already mentioned; for Valentin has, from these data, calculated that the blood may all pass through the heart in from 43¾ to 62½ seconds.

The estimate from the speed at which the blood may be seen moving in transparent parts is not opposed to this. For, as already stated (p. 108), though the movement through the capillaries may be very slow, yet the length of capillary vessel through which any portion of blood has to pass is very small. If we estimate that length at the tenth of an inch, and suppose the velocity of the blood therein to be only one inch per minute, then each por-

tion of blood may traverse its own distance of the capillary system in about six seconds. There would, thus, be plenty of time left for the blood to travel through its circuit in the larger vessels, in which the greatest length of tube that it can have to traverse in the human subject does not exceed ten feet.

All the estimates here given are averages; but of course the time in which a given portion of blood passes from one side of the heart to the other varies much, according to the organ it has to traverse. The blood which circulates from the left ventricle, through the coronary vessels, to the right side of the heart, requires a far shorter time for the completion of its course than the blood which flows from the left side of the heart to the feet, and back again to the right side of the heart; for the circulation from the left to the right cavities of the heart may be represented as forming a number of arches, varying in size, and requiring proportionately various times for the blood to traverse them; the smallest of these arches being formed by the circulation through the coronary vessels of the heart itself. The course of the blood from the right side of the heart, through the lungs, to the left, is shorter than most of the arches described by the systemic circulation, and in it the blood flows, *cæteris paribus*, much quicker than in most of the vessels which belong to the aortic circulation. For although the quantity of blood contained, at any instant, in the greater circulation of the body is far greater than the quantity within the lesser circulation, yet, in any given space of time, as much blood must pass through the lungs as passes in the same time through the systemic circulation. If the systemic vessels contain five times as much blood as the pulmonary, the blood in them must move five times as slow as in these; else, the right side of the heart would be either overfilled or not filled enough.

Peculiarities of the Circulation in different Parts.

The most remarkable peculiarities attending the circulation of blood through different organs are observed in the cases of the *lungs*, the *liver*, the *brain*, and the *erectile organs*. The pulmonary and portal circulations have been already alluded to (p. 72), and will be again noticed, when considering the functions of the lungs and liver.

The chief circumstances requiring notice in relation to the *cerebral circulation*, are observed in the arrangement and distribution of the vessels of the brain, and in the conditions attending the amount of blood usually contained within the cranium.

The functions of the brain seem to require that it should receive a large supply of blood. This is accomplished through the number and size of its arteries, the two internal carotids, and the two vertebrals. But it appears to be further necessary that the force with

which this blood is sent to the brain should be less, or, at least, subject to less variation from external circumstances, than it is in other parts. This object is effected by several provisions; such as the tortuosity of the large arteries, and their wide anastomoses in the formation of the circle of Willis, which will insure that the supply of blood to the brain may be uniform, though it may by an accident be diminished, or in some way changed, through one or more of the principal arteries. The transit of the large arteries through bone, especially the carotid canal of the temporal bone, may prevent any undue distension; and uniformity of supply is, further, insured by the arrangement of the vessels in the pia mater, in which, previous to their distribution to the substance of the brain, the large arteries branch and divide into innumerable minute ramuscles and capillaries, which, after frequent communications with one another, enter the brain, and carry into nearly every part of it uniform and equable streams of blood.

The arrangement of the *veins* within the cranium is also peculiar. The large venous trunks or sinuses are formed so as to be scarcely capable of change of size; and composed as they are of the tough tissue of the dura mater, and, in some instances, bounded on one side by the bony cranium, they are not compressible by any force which the fulness of the arteries might exercise through the substance of the brain; nor do they admit of distension when the flow of venous blood from the brain is obstructed.

The general uniformity in the supply of blood to the brain, which is thus secured, is well adapted, not only to its functions, but also to its condition as a mass of nearly incompressible substance placed in a cavity with unyielding walls. These conditions of the brain and skull have appeared, indeed, to some, enough to justify the opinion that the quantity of blood in the brain must be at all times the same; and that the quantity of blood received within any given time through the arteries must be always, and at the same time, exactly equal to that removed by the veins. In accordance with this supposition, the symptoms commonly referred to either excess or deficiency of blood in the brain, were ascribed to a disturbance in the balance between the quantity of arterial and that of venous blood. Some experiments performed by Dr. Kellie appeared to establish the correctness of this view. He believed that in animals bled to death, while all the other organs of the body were nearly emptied of blood, the vessels of the brain contained almost their ordinary quantity; but that if, previous to bleeding an animal, he made a hole in its cranium, and thus exposed the brain, equally with the other organs, to the influence of atmospheric pressure, its vessels, like those of other parts of the body, were emptied as the animal bled to death. But Dr. Burrows (lxxi. May, 1843, and xcv.) having repeated these experiments, and performed additional ones,

has obtained different results. He found that in animals bled to death, without any aperture being made in the cranium, the brain became pale and anæmic like other parts. And, in proof that, during life, the cerebral circulation is influenced by the same general circumstances that influence the circulation elsewhere, he found congestion of the cerebral vessels in rabbits killed by strangling or drowning; while in others, killed by prussic acid, he observed that the quantity of blood in the cavity of the cranium was determined by the position in which the animal was placed after death; the cerebral vessels being congested when the animal was suspended with its head downwards, and comparatively empty when the animal was kept suspended by the ears. He concluded, therefore, that although the total volume of the contents of the cranium is probably nearly always the same, yet the quantity of blood in it is liable to variation, its increase or diminution being accompanied by a simultaneous diminution or increase in the quantity of the cerebro-spinal fluid, which, by readily admitting of being removed from one part of the brain and spinal cord to another, and of being rapidly absorbed, and as readily effused, would serve as a kind of supplemental fluid to the other contents of the cranium, to keep it uniformly filled in case of variations in their quantity. (See also Eckr. cxxix.) But such variations occur only in a normal condition; in ordinary states, and in health, it is probable that the arrangements of the vessels, to which we have referred, insure to the brain a supply of blood which is both uniform and guarded from the accidental disturbances to which the supply for all other organs is liable even in circumstances consistent with health.

Erectile structure.—The instances of greatest variation in the quantity of blood contained, at different times, in the same organs, are found in certain structures which, under ordinary circumstances, are soft and flaccid, but, at certain times, receive an unusually large quantity of blood, become distended and swollen by it, and pass into the state which has been termed *erection*. Such structures are the corpora cavernosa and corpus spongiosum of the penis in the male, and the clitoris in the female; and, in a less degree, the nipple of the mammary gland in both sexes. The corpus cavernosum penis, which is the best example of an erectile structure, has an external fibrous membrane, or sheath, from the inner surface of which numerous fine lamellæ pass into the interior of the body, dividing its cavity into small compartments, which look like cells when they are inflated. Within these is situated the plexus of veins upon which the peculiar erectile property of the organ mainly depends. It consists of short veins, which very closely interlace and anastomose with each other in all directions, and admit of great variation of size, collapsing in the passive state of the organ, but, for erection, capable of an amount of dilatation which exceeds

beyond comparison that of the arteries and veins which convey the blood to and from them. The strong fibrous tissue lying in the intervals of the venous plexus, and the external fibrous membrane or sheath with which it is connected, limit the distension of the vessels, and, during the state of erection, give to the penis its condition of tension and firmness. The same general condition of vessels exists in the corpus spongiosum urethræ, but around the urethra the fibrous tissue is much weaker than around the body of the penis, and around the glans there is none. The venous blood is returned from the plexuses by comparatively small veins; those from the glans and the fore part of the urethra empty themselves into the dorsal vein of the penis; those from the corpus cavernosum pass into deeper veins, which issue from the corpora cavernosa at the crura penis; and those from the rest of the urethra and bulb pass more directly into the plexus of the veins about the prostate. For all these veins one condition is the same; namely, that they are liable to the pressure of muscles when they leave the penis. The vena dorsalis penis may be compressed by the uniting tendons of the ischio-cavernosi; the crura penis, and the veins issuing from them, are under the same muscles; and the veins of the bulb are subject to the compression of the bulbo-cavernosi. (See Krause, lxxx. 1837; Kobelt, cxxvii. and xxv. 1843-4, p. 58.)

Müller described a peculiar arrangement of the arteries of the corpora cavernosa; one set of them he described as the ultimate ramuscles, which terminate in the minute radicles of the veins, and are destined for the nutrition of the part: the others as coming off from the side of the arteries, and consisting of short tendril-like branches, terminating abruptly by a rounded, apparently closed extremity, turned back somewhat on itself. He named these *arteriæ helicinæ*, and thought they projected into the venous cells, as represented in the annexed figure. His account has been confirmed by Erdl (lxxx. 1841), but is denied by Valentin (lxxx. 1838) and Berres (cxxviii. 60, xxxi.), who think that what Müller called helicine arteries were small arteries running in the septa and bands of fibrous tissues which intercept the corpus cavernosum, and which, when cut or torn across, assume a contorted somewhat spiral figure.

Fig. 28.

Erection results from the distension of the venous plexuses with blood. The principal exciting cause, in the erection of the penis, is nervous irritation, originating in the part itself or derived from the brain and spinal cord. The nervous influence is communicated to the penis by the pudic nerves which ramify in its vascular tissue; and Guenther (xcvi. 1828, p. 364) has observed that, after their division in the horse, the penis is no longer capable of erection. It

affords a good example of the subjection of the circulation in an individual organ to the influence of the nerves; but the mode in which they excite a greater influx of blood is not with certainty known.

The most probable explanation is that recently offered by Professor Kölliker, who ascribes the distension of the venous plexuses to the influence of organic muscular fibres, which he finds in abundance in the corpora cavernosa of the penis, from the bulb to the glans, also in the clitoris and other parts capable of erection. While erectile organs are flaccid and at rest, these contractile fibres exercise an amount of pressure on the plexuses of vessels distributed amongst them sufficient to prevent their distension with blood. But when, through the influence of their nerves, these parts are stimulated to erection, the action of these fibres is suspended, and the plexuses thus liberated from pressure yield to the distending force of the blood, which probably at the same time arrives in greater quantity owing to a simultaneous dilatation of the arteries of the parts, and thus the plexuses become filled, and remain so until the stimulus to erection subsides, when the organic muscular fibres again contract, and so gradually expel the excess of blood from the previously distended vessels. The influence of cold in producing extreme contraction and shrinking of erectile organs, and the opposite effect of warmth in inducing fulness and distension of these parts, are among the arguments used by Kölliker in support of this opinion (cxci.).

The accurate dissections and experiments of Kobelt (cxxvii.), extending and confirming those of Le Gros Clark (lxxi. vol. xviii. p. 437) and Krause (lxxx. 1837), have shown that this influx of the blood, however explained, is the first condition necessary for erection, and that through it alone, much enlargement and turgescence of the penis may ensue. But the erection is probably not complete, nor maintained for any time, except when, together with this influx, the muscles already mentioned contract, and by compressing the veins, stop the efflux of blood, or prevent it from being as great as the influx.[1]

It appears, however, to be only the most perfect kind of erection that needs the help of muscles to compress the veins; for none such can assist the erection of the nipples, or that amount of turgescence just falling short of erection of which the spleen and many other parts are capable. For such turgescence nothing more seems

[1] Kölliker, however, seems to doubt the existence of any such additional influence in the production of erection, and believes that the mere accumulation of blood in the venous plexuses, in consequence of the relaxation of the muscular fibres by which they are surrounded, is sufficient to produce the distension and firmness characteristic of the erectile state.

than a large plexiform arrangement of the veins and such s may admit, upon local occasions, augmented quantities

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CHAPTER VI.

RESPIRATION.

blood circulates through the various parts of the body, its office by nourishing the several tissues and supplying ng organs the materials necessary for their different se- it is deprived of part of its nutritive constituents, and be- arged with impurities resulting from the deterioration of s. It is, therefore, necessary that fresh supplies of nutri- uld be continually added to the blood, and that provision e made for the removal of the impurities. The first of ects is accomplished by the processes of digestion and absorp- he second is principally effected by the agency of the excretory organs through which are removed the several es with which the blood is charged, whether these impuri- derived altogether from the degeneration of tissues, or in o, from the elements of unassimilated food. One of the portant and abundant of the impurities is carbonic acid, oval of which, and the introduction of fresh quantities of constitute the chief purpose of respiration—a process which, of its intimate relation to the circulation, may be considered her than with the other excretory functions.

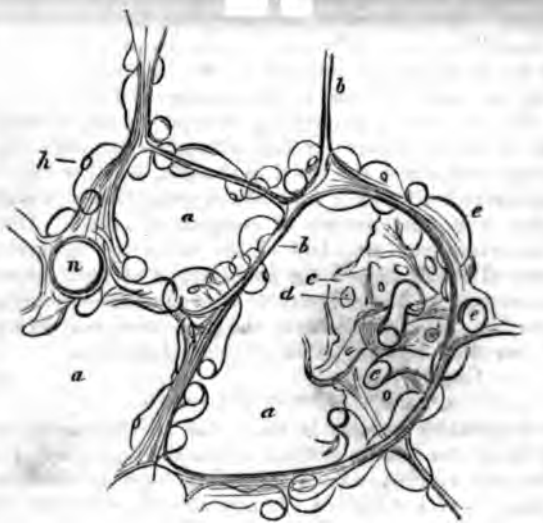
Structure of the Lungs.[1]

respiratory process in man, and all Mammalia, is chiefly on in the minute cavities within the lungs, called *air-cells*, onary vesicles. Each lobule, or small subdivision of the nsists of a collection of such air-cells, clustered upon and into minute branches of the bronchial tubes, and having alls overlaid with capillaries derived from the terminal s of the pulmonary artery.

bronchial tube belonging to each lung passes into its sub- dividing and subdividing, but without anastomosis, and branches to every part of the organ. All the larger branches lls formed of tough membrane with organic-muscular circu-

[1] best recent essays on the Structure of the Lungs are those by xli. vol. xxviii.); Addison (xliii. 1842); Bourgery (xix. 1842); tt (cxxi.); and Adriani (cxcvii.).

lar fibres, giving them some power of spontaneous contraction, portions of cartilaginous rings by which they are held open, and longitudinal bundles of elastic tissue for greater power of recoil after extension: they are lined with mucous membrane, the surface of which is covered with vibratile ciliary epithelium. But when the bronchi, by successive branchings, are reduced to about 1,100th of an inch in diameter, they lose these structures, and their walls are formed of only a tough, ... rane, with traces of fibrous, probably muscular,[1] structi ...ch the capillaries are spread in a very dense network, ...ous parts of which air-cells irregularly open. Tubes ... are named by Mr. Rainey *intercellular passages*. T... opening into them may be placed singly on their walls ...s from them (Fig. 29); but



View of a thin section of the lung of a cat, which had been injected by the pulmonary artery with gelatine, so as to fill bloodvessels and air-cells, and had been sliced when cold. *a a a.* Air-cells and lobular passage in section. *b b.* Their wall in section. *c.* Their wall in face. *d.* Extremely faint nucleus in the same. *e e.* Capillaries. *h.* Nucleus in wall of capillary. *n.* Small pulmonary artery or vein with simple wall. Magnified 250 diameters.

more often are arranged in rows like minuter sacculated tubes; so that a succession or series of cells, all opening into one another, open by a common orifice into the tube. The cells are of various

[1] Moleschott (cxxi.), and Kölliker (cxcii. 1849).

ording to the mutual pressure to which they are subject; are nearly in contact, and they vary from 1-120th to of an inch in diameter. (Moleschott, cxxi.) Their walls are fine membrane, similar to that of the intercellular pas- continuous with it, which is folded on itself so as to form lged border at each circular orifice of communication be- tiguous air-cells, or between the cells and the bronchial The cells have no epithelial lining; but on the exterior embrane of which they are constructed a network of pul- apillaries is spread out so densely that the interspaces or re even narrower than the vessels, which are, on an aver- 00th of an inch in diameter. Between the atmospheric e cells and the blood in these vessels nothing intervenes thin membranes of the cells and capillaries; and the expos- he blood to the air is the more complete because the folds brane between contiguous cells, and, often, the spaces be- e walls of the same, contain only a single layer of capillaries, les of which are thus at once exposed to the air.

ells situated nearest to the centre of the lung are smaller, r networks of capillaries are closer than those nearer to mference, in adaptation to the more ready supply of fresh e central than the peripheral portion of the lungs. The adjacent lobules do not communicate; and those of the same r proceeding from the same intercellular passage, do so as a rule only near angles of bifurcation; so that, when any l tube is closed or obstructed, the supply of air is lost for cells opening into it or its branches.

Movements of Respiration.

novements for taking into the lungs fresh air, and for ex- from them the air that has been changed by the respiratory are those of inspiration and expiration. The former is ed by the contraction of muscles bounding or attached to erior of the chest; the latter, chiefly and usually, by the contraction or recoil of the lungs and the walls of the chest, ey have been dilated in the act of inspiration.

chest is a cavity closed on every side from the entrance of immediate boundary is formed by its lining membrane, the its walls, external to the pleura, are partly osseous and un- , though movable, partly muscular, partly elastic. It is the lungs and heart and their larger vessels, and these fill ly in all its alterations of size; when it enlarges, they re- ore air and blood; when it contracts, air and blood pass out ; and the lungs and part of the heart are always in contact ry part of its internal surface. The changes produced by iratory movements on the circulation of blood have been

noticed already (p. 112); the much greater changes of air will now be alone considered.

Air, as already said, fills all the air-tubes and cells of the lungs, and through their medium the pressure of the atmosphere is communicated, through the open glottis, to the whole of the interior of the cavity of the chest, and balances the pressure of the atmosphere on the exterior of the chest. The force, therefore, which is required for the expansion of the chest in inspiration is not more than is necessary for moving the weight of its walls and those of the abdomen, and overcoming their elasticity and that of the lungs. The expressions which imply the necessity of forming a vacuum in the chest to draw in air, are inaccurate or exaggerated; the pressure of the atmosphere on both the inside and outside of the chest being equal, its walls are free to move so long as the glottis is open. When they are raised, so as to expand the chest, the pressure on the exterior of the lungs is made somewhat less than that of the atmospheric air on their interior: the excess of pressure, therefore, impels more air into them through the trachea. When, on the other hand, the walls of the chest contract, or allow the elastic tissue of the lungs and pulmonary pleura to contract, the pressure is greater on the exterior than on the interior of the lungs, and air is forced out of them through the trachea.

In its enlargement in inspiration the capacity of the chest is commonly increased in all directions; and chiefly in its vertical diameter and at its posterior part, so as to insure the expansion of the great masses of lung which lie in the hollows at the back of the chest, by the sides of the spine. But its mode of increase presents some peculiarities in different persons and circumstances. In young children, the inspiration is effected almost entirely by the diaphragm, which being highly arched in expiration, becomes flatter as it contracts, and descending presses on the abdominal viscera, and pushes forward the front walls of the abdomen. The movement of the abdominal walls being here more manifest than that of any other part, it is usual to call this the *abdominal mode* or *type* of respiration. In adult men, together with the descent of the diaphragm, and the pushing forward of the front wall of the abdomen, the lower part of the chest and the sternum are subject to a wide movement in inspiration. In women, the movement appears less extensive in the lower, and more so in the upper part of the chest; a mode of breathing to which a greater mobility of the first rib is adapted, and which may have for its object the provision of sufficient space for respiration when the lower part of the chest is encroached upon by the pregnant uterus. MM. Beau and Maissiat (cxxii. 1842–3), call the former the *inferior costal*, and the latter the *superior costal*, type of respiration; but the annexed diagrams from Mr. Hutchinson's paper (xli. vol. xxix.) will explain

the difference better than the names, which imply a greater diversity than naturally exists in the modes of inspiration.

Fig. 30. Fig. 31.

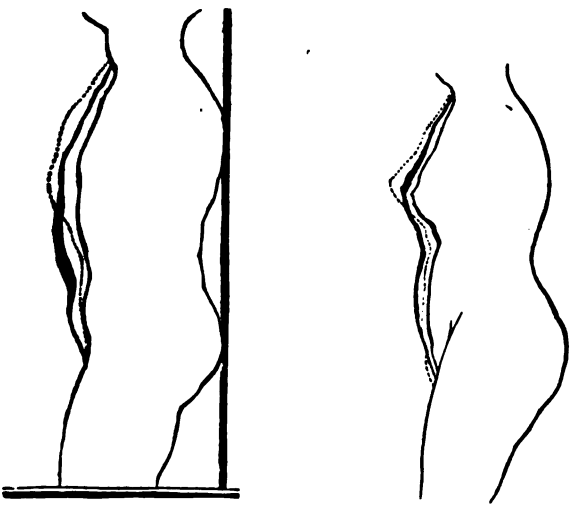


Fig. 30. The changes of the thoracic and abdominal walls of the male during respiration. The back is supposed to be fixed in order to throw forward the respiratory movement as much as possible. The outer black continuous line in front represents the ordinary breathing movement: the anterior margin of it being the boundary of *inspiration*, the posterior margin the limit of *expiration*. The line is thicker over the abdomen, since the ordinary respiratory movement is chiefly abdominal: thin over the chest, for there is less movement over that region. The dotted line indicates the movement on deep inspiration, during which the sternum advances while the abdomen recedes.

Fig. 31. The respiratory movement in the female. The lines indicate the same changes as in the last figure. The thickness of the continuous line over the sternum shows the larger extent of the ordinary breathing movement over that region in the female than in the male.

From the enlargement produced in inspiration, the chest and lungs return, with expiration, by their elasticity.[1] The costal car-

[1] For an account of the particular muscles engaged in inspiration, see the article *Thorax*, by Mr. Hutchinson, in the Cyclopædia of Anatomy; a paper on the Movements of Respiration, by Dr. Sibson, in the Medico-Chirurgical Transactions for 1848; and as well as these the student may refer to Mr. Hutchinson's paper in the twenty-ninth volume of the Medico-Chirurgical Transactions: Mr. Sibson's papers in the Philosophical Transactions for 1846, and the forty-first volume of the Medical Gazette; Dr. J. Reid's article *Respiration* in the Cyclopædia of Anatomy; and the papers of MM. Beau and Maissiat (cxxii. 1842 and 1848).

tilages are the chief seats of elastic power in the walls of the chest, and add to the force of an ordinary expiration, i. e., of such an one as is made in tranquil breathing. But the walls of the chest hinder deeper expirations, such as are made in straining, coughing, and the like; for these, muscular efforts are required, and when the chest is contracted or compressed by those efforts, it recovers its average capacity by its elasticity. Independently of its elasticity, the walls of the chest follow, in expiration, the elastic recoil or contraction of the lungs, which have elastic tissue in the bronchial tubes and air-cells and in their investing pleura, and are always kept on the stretch, ready to contract as soon as the muscular effort for expanding the chest ceases, contracting with the more force the more they have been expanded, and never in health contracting so much as they might, or as they do when the chest is opened and atmospheric pressure is directly admitted to their external surface.

The quantity of air that is changed in the lungs in each act of ordinary tranquil breathing is variable, and is very difficult to estimate, because it is hardly possible to breathe naturally while, as in an experiment, one is attending to the process. The best estimate, perhaps, is that by Mr. Coathupe (xciii. 1839) who states the quantity at from twenty to twenty-five cubic inches; and this is probably as near as possible to the truth in the case of healthy young and middle-aged men; but Bourgery (cxxii. 1843) is most likely right in saying that old people, even in health, habitually breathe more deeply, and change in each respiration a larger quantity of air than younger persons do.

This quantity, being that habitually and almost uniformly changed in breathing, is called by Mr. Hutchinson (xli. vol. xxix.) *breathing air.* The quantity over and above this which a man can draw into the lungs in the deepest inspiration, he names *complemental air:* its amount is various, as will be presently shown. After ordinary expiration, such as that which expels the *breathing air,* a certain quantity of air remains in the lungs, which may be expelled by a forcible and deeper expiration: this he terms *reserve air.* But, even after the most violent expiratory effort, the lungs are not completely emptied; a certain quantity always remains in them, over which there is no voluntary control, and which may be called *residual air.* Its amount depends in great measure on the absolute size of the chest, and has been variously estimated at from forty to two hundred and sixty cubic inches.

The greatest respiratory capacity of the chest is indicated by the quantity of air which a person can expel from his lungs by a forcible expiration after the deepest inspiration that he can make. Mr. Hutchinson names this the *vital capacity;* it expresses the power which a person has of breathing in the emergencies of active

exercise, violence, and disease; and in healthy men it varies according to *stature*, *weight*, and *age*.

It is found by Mr. Hutchinson, from whom nearly all our information on this subject is derived, that at a temperature of 60° F. 225 cubic inches is the average *vital capacity* of a healthy person, five feet seven inches in height. For every inch of height above this standard the capacity is increased, on an average, by eight cubic inches; and for every inch below, it is diminished by the same amount. This relation of capacity to height is quite independent of the absolute capacity of the cavity of the chest; for the cubic contents of the chest do not always, or even generally, increase with the stature of the body; and a person of small absolute capacity of chest may have a large capacity of respiration, and *vice versa*. The capacity of respiration is determined only by the mobility of the walls of the chest; but, why this mobility should increase in a definite ratio with the height of the body is yet unexplained; and must be difficult of solution, seeing that the height of the body is chiefly determined by that of the legs, and not by that of the trunk or the depth of the chest. But the vast number of observations made by Mr. Hutchinson leave no doubt of the fact, as stated above.

The influence of *weight* on the capacity of respiration is less manifest and considerable than that of height; and it is difficult to arrive at any definite conclusions on this point, because the natural average weight of a healthy man in relation to stature has not yet been determined. As a general statement, however, it may be said that the capacity of respiration is not affected by weights under 161 pounds, or 11½ stones; but that, above this point, it is diminished at the rate of one cubic inch for every additional pound up to 196 pounds, or 14 stones; so that, for example, while a man of five feet six inches, and weighing less than 11½ stones, should be able to expire 217 cubic inches, one of the same height, weighing 12½ stones, might expire only 203 cubic inches.

By *age*, the capacity appears to be increased from about the fifteenth to the thirty-fifth year, at the rate of five cubic inches per year; from thirty-five to sixty-five it diminishes at the rate of about one and a half cubic inch per year; so that the capacity of respiration of a man sixty years old would be about 30 cubic inches less than that of a man forty years old, of the same height and weight.

Mr. Hutchinson's observations were made almost exclusively on men; and his conclusions are, perhaps, true of them alone; for women, according to Bourgery, have only half the capacity of breathing that men of the same age have.

The *number* of respirations in a healthy adult person usually ranges from fourteen to eighteen per minute. According to Mr.

Hutchinson, the *force* with which the inspiratory muscles are capable of acting is greatest in individuals of the height of from five feet seven inches to five feet eight inches, and will elevate a column of three inches of mercury. Above this height, the force decreases as the stature increases; so that the average of men of six feet can elevate only about two and a half inches of mercury. The force manifested in the strongest expiratory acts is, on the average, one-third greater than that exercised in inspiration. But this difference is in great measure due to the power exerted by the elastic reaction of the walls of the chest; and it is also much influenced by the disproportionate strength which the expiratory muscles attain, through being called into use for other purposes than that of simple expiration. **The force of the inspiratory act is, therefore, better adapted than that of the expiratory for testing the muscular strength of the body.**

Much of the force exerted in inspiration is employed in overcoming the resistance offered by the elasticity of the walls of the chest and of the lungs. Mr. Hutchinson estimated the amount of this elastic resistance by observing the elevation of a column of mercury raised by the return of air forced, after death, into the lungs, in quantity equal to the known capacity of respiration during life; and he calculated that in a man capable of breathing 200 cubic inches of air, the muscular power expended upon the elasticity of the walls of the chest, in making the deepest inspiration, would be equal to the raising of at least 301 pounds avoirdupois. In tranquil respiration, supposing the amount of breathing air to be twenty cubic inches, the resistance of the walls of the chest would be equal to lifting more than 200 pounds. The elastic force exerted in ordinary expiration must therefore be much greater than enough to lift this weight; because in it the elastic force of the lungs is also in action—a force which is not included in these estimates, because the lungs were in both cases burst by the air forced into them.

It is probable that in the ordinary quiet respiration, which is performed without consciousness or effort of the will, the only forces engaged are those of the inspiratory muscles, and the elasticity of the walls of the chest and the lungs. And it is not known under what circumstances the contractile power which the bronchial tubes, and perhaps the air-cells, possess, by means of their organic muscular fibres, is brought into action. It is possible, as Dr. R. Hall (C. C.) has lately maintained, that it may assist in expiration; but it is more likely that its chief purpose is to regulate and adapt, in some measure, the quantity of air admitted to the lungs, and to each part of them, according to the supply of blood. Another purpose probably sometimes served by the muscular fibres of the bronchial tubes is that of contracting upon and

idually expelling collections of mucus, which may have accumu-
ed within the tubes, and cannot be ejected by forced expiratory
rts, owing to collapse or other morbid conditions of the portion
lung proceeding from the obstructed tubes. (Dr. W. T. Gairdner,
xxix. May, 1851.)

The muscular action in the lungs, morbidly excited, is probably
e chief cause of the phenomena of spasmodic asthma. It may
demonstrated by galvanizing the lungs shortly after taking them
m the body: under such a stimulus they contract so as to lift
water placed in a tube introduced into the trachea (C. J. B.
illiams, cxxxi. p. 588); and Volkmann (xv. art. *Nervenphysio-
gie*, p. 586), has shown that they may be made to contract by
mulating their nerves. He tied a glass tube, drawn fine at one
d, into the trachea of a beheaded animal, and when the small
d was turned to the flame of a candle, he galvanized the pneu-
ogastric trunk; each time he did so, the flame was blown, and
ce it was blown out.

The changes of the air in the lungs effected by these respiratory
ovements are assisted by the various conditions of the air itself.
cording to the law observed in the diffusion of gases, the car-
nic acid evolved in the air-cells will, independently of any respi-
tory movement, tend to leave the lungs, by diffusing itself into
e external air where it exists in less proportion; and, according
the same law, the oxygen of the atmospheric air will tend of
elf towards the air-cells in which its proportion is less than in
e air in the bronchial tubes or external to the body. But for
is tendency of the oxygen and carbonic acid to mix uniformly,
thin and without the lungs, the *reserve* and *residual* air would,
obably, be very injuriously charged with carbonic acid; for the
spiratory movements alone are not enough to empty the air-cells,
d perhaps expel only the air which lies in the larger bronchial
bes. Probably also the change is assisted by the different tem-
rature of the air within and without the lungs; and by the
tion of the cilia on the mucous membrane of the bronchial tubes,
e continual vibrations of which may serve to prevent the adhe-
on of the air to the moist surface of the membrane.

Movement of the Blood in the Respiratory Organs.

To meet the air thus alternately moved into and out of the air-
lls and minute bronchial tubes, the blood is propelled from the
ght ventricle through the pulmonary capillaries in steady streams,
d slowly enough to permit every minute portion of it to be for a
w seconds exposed to the air, with only the thin walls of the
pillary vessels and air-cells intervening. The pulmonary circula-
on is of the simplest kind; for the pulmonary artery branches
gularly; its successive branches run in straight lines, and do not

anastomose; the capillary plexus is uniformly spread over the si cells and intercellular passages; and the veins derived from it pu ceed in a course as simple and uniform as that of the arteries, thei branches converging, but not anastomosing. The veins have n valves, or only small imperfect ones prolonged from their angles junction, and incapable of closing the orifice of either of the ves between which they are placed. The pulmonary circulation also i unaffected by changes of atmospheric pressure, and is not expos to the influence of the pressure of muscles: the force by which i is accomplished, and the course of the blood, are alike simple.

The blood carried through the pulmonary artery, being venou till it comes to the capillaries, is unfit for the nutrition of any par of the lungs, except those in which it flows through the capillaries to these it probably supplies nutritive materials as soon as it is itse arterialized. For the nutrition of the rest of the lungs, includin the pleura, interlobular tissue, bronchial tubes and glands, and th walls of the larger bloodvessels, a special supply of arterial bloo is furnished through one or two bronchial arteries, the branches which ramify in all these parts. The blood of the bronchial arter when, having served for the nutrition of these parts, it has becom venous, is carried, partly, into the branches of a bronchial vei distributed in the parts about the root of the lung, and partly in the small branches of the pulmonary artery, or, more directly, in the pulmonary capillaries, whence, being with the rest of the blood arterialized, it is carried to the pulmonary veins and left si of the heart.

Changes of the Air in Respiration.

By their contact in the lungs the composition of both air a blood is changed. The alterations of the former being manife simpler than those of the latter, and in some degree illustrative them, may be considered first.

The *atmosphere* we breathe has, in every situation in which has been examined in its natural state, an uniform compositio It appears to be a mixture of oxygen, nitrogen, carbonic acid, a watery vapor. Of every 100 volumes of pure atmospheric air, volumes (on an average) consist of nitrogen, the remaining 21 oxygen: but the proportions of these gases are subject to variatio of 2 or 3 parts in 1000, in situations where the oxygen is mu exposed to absorption, as over the sea when there is no wind. (Lew xviii. 1842.) The proportion of carbonic acid is extremely sma 10,000 volumes of atmospheric air contain, according to M. Saussure, only 4.15 of carbonic acid. In the open country, found the maximum proportion of this gas to be 5.74, the mi mum 3.15 in 10,000 parts. In the town of Geneva, the air co tained 0.31 more carbonic acid than in the country. M. Bouss

however, has lately found (xii. 1844), from numerous analy-
nich are confirmed by those of M. Lewy, that the quantity of
ic acid in the air of Paris (which may be taken as an exam-
a large town), is not above the average of the quantity con-
in the air of the country. This average he finds to be 3.97
es in 10,000; and his estimate may be considered gene-
rue, except for localities, such as mines, crowded rooms, vol-
districts, and others in which large quantities of carbonic acid
nstantly exhaling.
: quantity of watery vapor varies greatly, according to the
rature, and other circumstances, but some is never absent
the atmosphere. Besides these, its constant constituents, the
phere usually contains minute fractional quantities of ammo-
nd other accidental substances; but, as far as is at present
n, none of these have any particular relation to the respira-
process, and the consideration of them may therefore be
ed.
e changes produced by respiration on the atmospheric air are,
l, it is warmed; 2, its carbonic acid is increased; 3, its oxy-
s diminished; 4, its watery vapor is increased.

The expired air, heated by its contact with the interior of the
, is (at least in most climates) hotter than the inspired air.
mperature varies between 97° and 99½°, the lower tempera-
being observed when the air has remained but a short time in
ngs rather than when it was inhaled at a very low tempera-
for whatever the temperature when inhaled may be, the air
y acquires that of the blood before it is expelled from the
.

The carbonic acid in respired air is always increased; but
uantity exhaled in a given time is subject to change from
us circumstances. It may be stated, as a general average,
ed from the results of experiments of Valentin and Brunner
ol. i. 547), that, under ordinary circumstances, the quantity
is gas exhaled into the air breathed by a healthy adult man
nts to 1345.3 cubic inches, or about 636 grains per hour.
rding to this estimate, which corresponds very closely with
ne furnished by Sir H. Davy, and does not widely differ from
obtained by Allen and Pepys, and by Lavoisier, the weight of
n excreted from the lungs is about 173 grains per hour, or
ces in the course of twenty-four hours. Andral and Gavar-
ix.) calculate the average quantity of carbon excreted from
ngs of a healthy adult man at 9 ounces per day. Mr. Coa-
(xciii. 1839) makes it scarcely 5 ounces; while Liebig (xi.
t. p. 14) estimates the total quantity excreted from the lungs
2

and skin together at 13.9 ounces. Some of these discrepancies may be due to the variations to which the exhalation of carbonic acid is liable in different circumstances; for, even in health, the quantity varies according to age, sex, diversities in the respiratory movements, external temperature, the degree of purity of the respired air, and other circumstances. Each of these circumstances deserves a brief notice, because they afford evidence concerning either the sources of the carbonic acid exhaled, or the mode in which it is separated from the blood.

a. Influence of Age and Sex.—According to Andral and Gavarret (cix.), the quantity of carbonic acid exhaled into the air breathed by males, regularly increases from eight to thirty years of age; from thirty to forty it is stationary or diminishes a little; from forty to fifty the diminution is greater; and from fifty to extreme age it goes on diminishing till it scarcely exceeds the quantity exhaled at ten years old. In females (in whom the quantity exhaled is always less than in males of the same age), the same regular increase in quantity goes on from the eighth year to the age of puberty, when the quantity abruptly ceases to increase, and remains stationary so long as they continue to menstruate. When, however, menstruation has ceased, either in advancing years, or in pregnancy, or morbid amenorrhœa, the exhalation of carbonic acid again augments; but when menstruation ceases naturally, it soon decreases again at the same rate as it does in old men.

b. Influence of Respiratory Movements.—According to Dr. Vierordt (cx.), the more quickly the movements of respiration are performed the smaller is the proportionate quantity of carbonic acid contained in each volume of the expired air. Thus he found, that, with six respirations per minute, the quantity of expired carbonic acid was 5.528 per cent.; with twelve respirations, 4.262 per cent.; with twenty-four, 3.355; with forty-eight, 2.984; and with ninety-six, 2.662. Although, however, the proportionate quantity of carbonic acid is thus diminished during frequent respiration, yet the absolute amount exhaled into the air within a given time is increased thereby, owing to the larger quantity of air which is breathed in the time. This is the case, whether the respiration be voluntarily accelerated or is naturally increased in frequency, as it is after feeding, active exercise, &c. By diminishing the frequency and increasing the depth of respiration, the percentage proportion of carbonic acid in the expired air is diminished; being in the deepest respiration as much as 1.97 per cent. less than in ordinary breathing. But for this proportionate diminution, also, there is a full compensation in the greater total volume of air which is thus breathed. Finally, the last half of a volume of expired air contains more carbonic acid than the half first expired; a circumstance which is explained by the one portion of air coming from the remote

of the lungs, where it has been in more immediate and pro-
d contact with the blood than the other has, which comes
y from the larger bronchial tubes.

Influence of external Temperature.—The observations made
ierordt, at various temperatures between 38° F. and 75° F.,
that within this range every rise equal to 10° F. causes a
ıation of about two cubic inches in the quantity of carbonic
exhaled per minute. Letellier (xii. 1845), from experiments
rmed on animals at much higher and lower temperatures than
bove, also finds that the higher the temperature of the respired
ıs far as 104° F.), the less is the amount of carbonic acid ex-
l into it, whilst the nearer it approaches zero the more does the
ınic acid increase. The greatest quantity exhaled at the lower
eratures he found to be about twice as much as the smallest
led at the higher temperatures.

Purity of the respired Air.—The average quantity of carbonic
given out by the lungs constitutes about 4.48 per cent. of the
red air, but if the air which is breathed be previously impreg-
d with carbonic acid (as is the case when the same air is fre-
ıtly respired), then the quantity of carbonic acid exhaled be-
es much less. This is shown by the results of two experiments
ormed by Allen and Pepys (xliii. 1808–9). In one, in which
h air was taken in at each inspiration, thirty-two cubic inches
arbonic acid were exhaled in a minute; whilst in the other, in
:h the same air was respired repeatedly, the quantity of carbonic
emitted in the same time was only 9.5 cubic inches. They
ıd also that however often the same air may be respired, even
ıntil it will no longer sustain life, it does not become charged
ı more than 10 per cent. of carbonic acid. The necessity of a
ıtant supply of fresh air, by means of ventilation, through rooms
hich many persons are breathing together, or in which, from
other source, much carbonic acid is evolved, is thus rendered
ious; for even when the air is not completely irrespirable, yet
he same proportion as it is already charged with carbonic acid,
s the further extrication of that gas from the lungs suffer hin-
nce.

The *period of day* seems to exercise a slight influence on the
ıunt of carbonic acid exhaled in a given time, though beyond
fact that the quantity exhaled is much less by night than by
, we are scarcely yet in a position to state that variations in the
ıunt exhaled occur at uniform periods of the day, independent
he influence of other circumstances. By the *use of food* the
ntity is increased, whilst by fasting it is diminished; and, ac-
ling to Regnault and Reiset, it is greater when animals are fed
farinaceous food than when fed on meat. Spirituous drinks,
cially when taken on an empty stomach, produce an immediate

and marked diminution in the quantity of this gas exhaled. *Bodily exercise*, in moderation, increases the quantity to about one-third more than it is during rest; and for about an hour after exercise the volume of the air expired in the minute is increased about 118 cubic inches: and the quantity of carbonic acid about 7.8 cubic inches per minute. During *sleep*, on the other hand, there is a considerable diminution in the quantity of this gas evolved; a result probably in great measure dependent on the tranquillity of the breathing: directly after waking, there is a great, though quickly transitory, increase in the amount exhaled. A larger quantity is exhaled when the barometer is low than when it is high.

3. *The Oxygen in respired air is always less* than in the same air before respiration, and its diminution is generally proportionate to the increase of the carbonic acid. The experiments of Valentin and Brunner (iv. Bd. i.) seem to show that for every volume of carbonic acid exhaled into the air, 1.17421 volumes of oxygen are absorbed from it; and that when the average quantity of carbonic acid, *i. e.*, 1345.3 cubic inches, or 635.85 grains, is exhaled in the hour, the quantity of oxygen absorbed in the same time is 1583.6 cubic inches, or 541.5 grains. According to this estimate, there is more oxygen absorbed than is exhaled with carbon in the carbonic acid, for oxygen combines with carbon to form carbonic acid without change of volume; and to this general conclusion, namely, that the volume of air expired in a given time is less than that of the air inspired (allowance being made for the expansion in being heated), and that the loss is due to a portion of oxygen absorbed and not returned in the exhaled carbonic acid, all observers agree, though as to the actual quantity of oxygen so absorbed they differ even widely.

The quantity of oxygen that does not combine with the carbon given off in carbonic acid from the lungs, is probably disposed of in forming some of the carbonic acid and water given off from the skin, and in combining with sulphur and phosphorus to form part of the acids of the sulphates and phosphates excreted in the urine, and probably, also, from the experiments of Dr. Bence Jones (vi. April, 1851, and lxxxviii. August 30, 1851), with the nitrogen of the decomposing nitrogenous tissues.

The quantity of oxygen consumed seems to vary much not only in different individuals, but in the same individual at different periods: thus it is considerably influenced by food, being greater in dogs when fed on farinaceous than on animal food, and much diminished during fasting, while it varies at different stages of digestion. Animals of small size consume a relatively much greater amount of oxygen than larger ones. The quantity of oxygen in the atmosphere surrounding animals, appears to have very little influence on the

ount of this gas absorbed by them, for the quantity consumed not greater even though an excess of oxygen be added to the nosphere experimented with. (Regnault and Reiset, exc. July, 50, p. 252.)

Valentin and Brunner's estimates of the interchange of the ygen and carbonic acid in respiration, led them to believe that e exchanged quantities of the two gases are always in the propor- on of their *diffusion-volumes;* a conclusion which, if it were tablished, would justify us in explaining the process of respira- on as one due only to the properties of the gases, and their tendency diffuse or mingle with one another in certain fixed proportions y volume. But the grounds are not yet strong enough for so eighty a conclusion; and against it appear the many instances of eviation from the law, which seem proved by good experiments.[1] f the exchange of gases were according to the law of diffusion, heir proportions ought never to vary; however much the circum- tances of the general economy might change the quantity of one as of the carbonic acid in the instances already quoted), the quantity f the other should be equally and at the same time changed. Whereas, in many experiments, and even in some of Valentin's, he proportion of oxygen absorbed has been less or more than, ccording to the law of diffusion, it should have been. Especially, he experiments of Dulong and Despretz seemed to show that, in Carnivora, the oxygen absorbed always bears a larger proportion to he carbonic acid evolved than it does in Herbivora; and the recent areful experiments of Regnault and Reiset (xviii. 1848) confirm his, while they in no case show such a proportion between the ases exchanged as, according to the law of diffusion, there should e. They show that in the dog for every 100 parts of carbonic cid formed in twenty-four hours, 134.3 parts of oxygen were, on he average, absorbed; and in the rabbit and hen for every 100 arts of carbonic acid, 109.34 parts of oxygen; while, according o the diffusion-law, the proportion should be always 117.42 parts f oxygen to 100 of carbonic acid.

It may be added, that the conditions of the gases engaged in espiration are not those in which the law of diffusion would exactly old. The law requires that both gases should be free and under qual pressure; while, in the actual case, the gas in the blood is lissolved, under pressure, and separated by a membrane from that nto which it is to diffuse. It is possible that these peculiarities of he conditions may account for the deviations from the law while t is really in operation; but many more facts than are yet ascer- ained will be necessary to prove this.

[1] The objections to Valentin's theory, and his answers to them, are all i his Annual Reports on Physiology, in Canstatt's Jahresberichte, since 1

The Nitrogen of the atmosphere, in relation to the respiratory process, is supposed to serve only mechanically, by diluting the oxygen, and moderating its action upon the system. This purpose, or the mode of expressing it, has been lately denied by Liebig (xi. 8d edit. p. 184), on the ground that, if we suppose the nitrogen removed, the amount of oxygen in a given space would not be altered. But although it be true that if all the nitrogen of the atmosphere were removed, and not replaced by any other gas, the oxygen might still extend over the whole space at present occupied by the mixture of which the atmosphere is composed; yet since, under ordinary circumstances, oxygen and nitrogen, when mixed together in the ratio of one volume to four, produce a mixture which occupies precisely five volumes, with all the properties of atmospheric air, it must result that a given volume of atmosphere drawn into the lungs contains four-fifths less weight of oxygen than an equal volume composed entirely of oxygen. The greater rapidity and brilliancy with which combustion goes on in an atmosphere of oxygen than in one of common air, and the increased rapidity with which the ordinary effects of respiration are produced when oxygen instead of atmospheric air is breathed, seem to leave no doubt that the nitrogen with which the oxygen of the atmosphere is mixed has the effect of diluting this gas, in the same sense and degree as one part of alcohol is diluted when mixed with four parts of water.

It has been often discussed whether nitrogen be ever absorbed or exhaled from the atmosphere in respiration. That it may, in some conditions, be either absorbed or exhaled is proved by experiments of Allen and Pepys, who found that when guinea-pigs were made to breathe in a mixture of oxygen and hydrogen, nitrogen was exhaled, and in a quantity exceeding the volume of the whole body of the animal. The lower animals also, especially insects, are said to exhale nitrogen (Treviranus, xxxii. p. 330, Am. Ed.), and fishes to absorb it from the water in which they breathe, though they do not absorb hydrogen. (Humboldt, xxxii. p. 330, Am. Ed.)

But we cannot, from these facts, safely conclude what is the case in the ordinary conditions of life. In the earlier experiments, it seemed as if small quantities of nitrogen were sometimes absorbed, and sometimes exhaled, in respiration in atmospheric air. The later experiments of M. Boussingault (xviii. 1846), on turtle-doves, would prove that, besides the nitrogen excreted from the digestive canal and kidneys, nearly 2½ grains are daily discharged from the skin and lungs; and those of MM. Regnault and Reiset (xviii. 1848, and liii. 1849) on dogs, rabbits, and fowls, prove constantly a certain exhalation of nitrogen, the proportion seeming to vary according to the nature of the food, while they also find that during prolonged fasting, nitrogen instead of being exhaled is absorbed.

4. *Watery Vapor* is, under ordinary circumstances, always exhaled from the lungs in breathing. The quantity emitted is, as a general rule, sufficient to saturate the expired air (Valentin, iv. Bd. i. p. 547), or very nearly so (Moleschott, cxxi.). Its absolute amount is, therefore, influenced by the following circumstances. First, by the volume of air expired; for the greater this is, the greater also will be the quantity of moisture exhaled. Secondly, by the quantity of watery vapor contained in the air previous to its being inspired; because the greater this is, the less will be the amount required to complete the saturation of the air. Thirdly, by the temperature of the expired air: for the higher this is the greater will be the quantity of watery vapor required to saturate the air. Fourthly, by the length of time which each volume of inspired air is allowed to remain in the lungs; for it seems probable that, although during ordinary respiration the expired air is always saturated with watery vapor, yet when respiration is performed very rapidly the air has scarcely time to be raised to the highest temperature, or be fully charged with moisture ere it is expelled.

For ordinary cases, however, it may be held that the expired air is saturated with watery vapor, and hence is derivable a means of estimating the quantity exhaled in any given time; namely, by subtracting the quantity contained in the air inspired from the quantity which (at the same barometric pressure) would saturate the same air at the temperature of expiration, which is ordinarily about 99°. And, on the other hand, if the quantity of watery vapor in the expired air be estimated, the quantity of air itself may from it be determined, being as much as that quantity of watery vapor would saturate at the ascertained temperature and barometric pressure.

The quantity of water exhaled from the lungs in twenty-four hours ranges (according to the various modifying circumstances already mentioned) from about 3000 to 13,000 grains (6 to 27 ounces). Some of this is probably formed by the combination of the excess of oxygen absorbed in the lungs with the hydrogen of the blood; but the far larger proportion of it must be the mere exhalation of the water of the blood, taking place from the surface of the air-passages and cells, as it does from the free surfaces of all moist animal membranes, particularly at the high temperature of warm-blooded animals. It is exhaled from the lungs whatever be the gas respired, continuing to be expelled even in hydrogen gas.

Changes produced in the Blood by Respiration.

The most obvious change which the blood undergoes in its passage through the lungs is that of *color*, the dark crimson of venous blood being exchanged for the bright scarlet of arterial blood. The circumstances which have been supposed to give rise

to this change, the conditions capable of effecting it independent of respiration, and some other differences between arterial and venous blood, were discussed in the chapter on BLOOD (page 59). The change in color is, indeed, the most striking, and may appear the most important, which the blood undergoes in its passage through the lungs; yet, perhaps, its importance is very little, except so far as it is an indication of other and essential alterations effected in the composition of the blood. Of these alterations the principal are, 1st, that the blood after passing through the lungs is 1° or 2° warmer than it was before; 2d, that it coagulates sooner and more firmly, and contains, apparently, more fibrine; 3d, that it contains more oxygen, less carbonic acid, and less nitrogen.

The difference last named is, probably, the most important. It might be assumed from what has been said of the changes in the inspired air, and it is proved, at least in regard to the first two gases, by examination of the blood itself.

The existence of carbonic acid in both arterial and venous blood has been proved by several experimenters, who have obtained appreciable quantities of it by exposing the blood to the vacuum of the air-pump, or, more certainly, by agitating it with atmospheric air, oxygen, or other gases, such as hydrogen or nitrogen. By the latter process carbonic acid may always be extracted from venous blood. Some, indeed, have failed to procure any gas from blood by means of the air-pump; but this may be explained by the fact observed by Magnus, that carbonic acid is not given out until the air in which the blood is placed is so rarefied that it supports only one inch of mercury. Heat also, commonly fails to evolve carbonic acid from blood: probably because, as also observed by Magnus, a temperature high enough to set free this gas coagulates the albumen of the blood, and if albumen, impregnated with carbonic acid, is once coagulated, the gas cannot be separated from it again by means of heat.

The uncertainty of former experiments is corrected by the recent researches of Magnus (xvii. 1845), from which it appears sure that carbonic acid, oxygen, and nitrogen exist, both in arterial and venous blood. Their relative proportions differ in the two kinds of blood. The quantity of oxygen contained in arterial blood is twice as great as that in venous blood; being equal to from 10 to 10½ per cent. of the volume of the former, and only about 5 per cent. of the volume of the latter. The quantity of carbonic acid, on the other hand, is less in arterial than in venous blood, amounting to about 20 volumes per cent. in the former, and 25 per. cent. in the latter. The quantity of nitrogen contained in the blood varies from about 1.7 to 3.3 per cent.: its relative proportion in arterial and in venous blood does not appear to differ much; but

from its being commonly exhaled in small quantity from the lungs, it may be believed to be greater in the venous blood.

These facts are supported by those already mentioned, concerning the exhalation of nitrogen by animals breathing in oxygen and hydrogen, and of carbonic acid by frogs breathing in nitrogen. The gases could not be so exhaled did they not exist in solution in the blood. And there can therefore be little doubt which of the proposed *theories of respiration* should be chosen for the explanation of the process. Till the existence of the gases in the blood was clearly proved, the theory most favored was, that the oxygen of the atmospheric air permeates the membranous walls of the air-cells, enters the blood, and there at once combines with carbon derived from the disintegrated tissues, to form carbonic acid, which escapes, together with the greater part of the nitrogen previously absorbed from the atmosphere. It could be well objected, even when the existence of gases in the blood was doubtful, that if this theory were true, the lungs ought to be much warmer than other parts of the body, through the quantity of heat given out in the quick union of the carbon with the oxygen of the atmosphere; and that such was not found to be the case: the temperature of the blood in the left side of the heart being never more than one or two degrees higher than that in the right.

Lagrange and Hassenfratz (xxxii. p. 350), impressed with this and other objections, proposed the theory which, with some modifications, has been more recently advocated by Magnus and others, and has been shown by them to be sufficient for the explanation of most of the phenomena yet observed in this part of the respiratory process. According to this theory, the oxygen absorbed into the blood from the atmospheric air in the lungs, is in part dissolved, and probably, also, in part loosely combined chemically with one or other of its ingredients. In this condition the oxygen is carried in the arterial blood to the various parts of the body, and with it, is, in the capillary system of vessels, brought into near relation or contact with the elementary parts of the tissues. Herein, co-operating probably in the process of nutrition, or the removal of disintegrated parts of the tissues, about one-half of the oxygen which the arterial blood contains disappears, and a proportionate quantity of carbonic acid and water is formed. The venous blood, containing the new-formed carbonic acid, returns to the lungs, where a portion of the carbonic acid is exhaled, and a fresh supply of oxygen is again taken in.

Whether part, or the whole, of the oxygen absorbed during respiration is at once united chemically with any of the constituents of the blood has not been determined. By some it is supposed to combine with the red corpuscles, by others with the fibrine. It appears most probable that the greater part of the gas is held in

solution by the fluid part of the blood: if combined, it must be very loosely so, till it reaches the capillaries. The same may be said with respect to the carbonic acid. How the exchange of the gases is effected has been already considered; if the diffusion theory be not received, we must suppose the emission and imbibition to be effected after the plan of the secretion and absorption of fluids by other organs; a supposition which is favored by the close analogy in structure between the lungs and the secreting glands.

Influence of the Nervous System in Respiration.

The respiratory functions are in two respects subject to the influence of the nervous system: namely, 1st, in the movements for the introduction and exit of air; and, 2dly, in the interchange of the gases. These will be more particularly considered in the sections on the MEDULLA OBLONGATA and PNEUMOGASTRIC NERVE. It may suffice to state here, that the respiratory movements and their regular rhythm, so far as they are involuntary and independent of consciousness (as in all ordinary occasions they are), are under the absolute governance of the medulla oblongata, which, as a nervous centre, receives the impression of the "necessity of breathing," and reflects it to the phrenic and such other motor nerves as will bring into co-ordinate and adapted action the muscles necessary to inspiration.

But the respiratory movements may be voluntarily performed or variously directed, and the mind may be conscious of the necessity of breathing, either when it attends the sensations to which that necessity gives rise, or when those sensations are more than commonly intense. In these cases, we may believe that the brain, as well as the medulla oblongata, is engaged in the process; for we have no evidence of the mind exercising either perception or will through any other organ than the brain. But even when the brain is thus in action, it appears to be the medulla oblongata which combines the several respiratory muscles to act together. In such acts, for example, as those of coughing and sneezing, the mind must first perceive the irritation at the larynx or nose, and exercise a certain degree of will in determining the actions, as, *e. g.*, in the taking of the deep inspiration that always precedes them. But the mode in which the acts are performed, and the combination of muscles to effect them, are determined by the medulla oblongata, independent of the will, and have the peculiar character of reflex involuntary movements, in being always, and without practice or experience, precisely adapted to the end or purpose.

In these and in all the other extraordinary respiratory actions, such as are seen in dyspnœa, or in straining, yawning, hiccough, and others, the medulla oblongata brings into adapted combination

of action many other muscles besides those commonly exerted in respiration. Almost all the muscles of the body, in violent efforts of dyspnœa, coughing, and the like, may be brought into action at once, or in quick succession; but, more particularly, the muscles of the larynx, face, scapula, spine, and abdomen, co-operate in these efforts with the muscles of the chest. These, therefore, are often classed as secondary muscles of respiration; and the nerves supplying them, including, especially, the facial, pneumogastric, spinal accessory, and external respiratory nerves, were classed by Sir Charles Bell with the phrenic, as the respiratory system of nerves. There appears, however, no propriety in making a separate system of these nerves, since their mode of action is not peculiar, and many beside them co-operate in the respiratory acts. That which is peculiar in the nervous influence directing the extraordinary movements of respiration is, that so many nerves are combined towards one purpose by the power of a distinct nervous centre, the medulla oblongata. In other than respiratory movements, these nerves may act singly or together, without the medulla oblongata; but, after it is destroyed, no movement adapted to respiration can be performed by any of the muscles, even though the part of the spinal cord from which they arise be perfect. The phrenic nerves, for example, are unable to excite respiratory movements of the diaphragm when their connection with the medulla oblongata is cut off, though their connection with the spinal cord may be uninjured.

The influence exercised through the pneumogastric nerves upon the functions of the lungs cannot be considered separately from their relation to the muscles of the larynx, and must therefore be deferred to the section particularly treating of the nerves.

Effects of the Suspension and Arrest of Respiration.

These deserve some consideration, because of the illustration which they afford of the nature of the normal processes of respiration and circulation. When the process of respiration is stopped, either by arresting the respiratory movements, or permitting them to continue in an atmosphere deprived of uncombined oxygen, the circulation of blood through the lungs is retarded, and, at length, stopped. The immediate effect of such retarded circulation is an obstruction to the exit of blood from the right ventricle: this is followed by delay in the return of venous blood to the heart; and to this succeeds venous congestion of the nervous centres, and all the other organs of the body. In such retardation, also, an unusually small supply of blood is transmitted through the lungs to the left side of the heart; and this small quantity is venous.

The condition, then, in which a suffocated animal dies is, commonly, that the left side of the heart is nearly empty, while the lungs, right side of the heart, and other organs are gorged with

venous blood. To this condition many things contribute. 1. The obstructed passage of blood through the lungs, which appears to be the first of the events leading to suffocation, seems to depend on the cessation of the interchange of gases, as if blood charged with carbonic acid could not pass freely through the pulmonary capillaries. That such may be the case, is shown by Mr. Wharton Jones's observation that the circulation in the web of the frog's foot, may be retarded or arrested by directing on the web a stream of carbonic acid, under the influence of which, the blood-corpuscles appear to cluster and stagnate in the vessels. But the stagnation of blood in the pulmonary capillaries would not be enough to stop the circulation, unless the actions of the heart were also weakened; for Mr. Erichsen (xciv. vol. lxiii. p. 22), having pithed dogs, and tied the right bronchus, and maintained artificial respiration in the left lung, found that, so long as the heart's action continued, nearly as much black blood flowed through a right pulmonary vein, as red blood through a left one.

Therefore, 2dly, the fatal result is due, in some measure, to the weakened action of the right side of the heart, in consequence, probably, of its over-distension by blood continually flowing into it; this flow being, probably, much increased by the powerful but fruitless efforts continually made at inspiration. (Eccles., lxxi. vol. xliv. p. 657.)

Thirdly, because of the obstruction at the right side of the heart, there must be venous congestion in the medulla oblongata and nervous centres; and this evil is augmented by the left ventricle receiving and propelling none but venous blood. Hence, slowness and disorder of the respiratory movements, and the movements of the heart, may be added. But this alone does not explain asphyxia, for Mr. Erichsen found that a dog was asphyxiated in the ordinary time, although arterial blood was made to circulate through the nervous centres during the whole time. However, under all these conditions combined, the heart at length ceases to act. The time at which the complete cessation ensues is uncertain. The domestic Mammalia usually perish, after submersion in water, in about three minutes: there are exceptional cases, in which animals and human beings have been revived, after being under water for a longer period. According to Mr. Erichsen (l. c. p. 30), in dogs suffocated by drowning, the voluntary movements cease in 1¾ minutes; the involuntary in 2¼ after submersion; the ventricular contractions continue for a period, ranging from 6½ to 14 minutes, the average time being 9¼ minutes; and the blood in the arteries becomes as black as that in the veins, in about 1½ minutes. In the human subject, he thinks that the ventricular contractions always cease at or before the expiration of five minutes after complete submersion; for persons are rarely, if ever saved, if they have been

ler water more than four minutes. The instances in which re-
ery has taken place after a longer immersion are probably to be
lained by the occurrence of fainting at the moment of the acci-
t; for, with the circulation enfeebled, the deprivation of air
y be endured much longer than it can while the blood still cir-
ates quickly, and accumulates carbonic acid.
It is to the accumulation of carbonic acid in the blood, and its
rveyance into the organs that we must, in the first place, ascribe
e phenomena of asphyxia. For when this does not happen, all
e other conditions may exist without injury; as they do, for
mple, in hybernating, warm-blooded animals. In these, life is
pported for many months in atmospheres in which the same
imals, in their full activity, would be speedily suffocated. During
e periods of complete torpor, their respiration entirely ceases;
e heart acts very slowly and feebly; the processes of organic life
e all but suspended, and the animal may with impunity be com-
etely deprived of atmospheric air. Spallanzani kept a marmot,
this torpid state, immersed for four hours in carbonic acid gas,
ithout its suffering any apparent inconvenience. Dr. Marshall
lall kept a lethargic bat under water for sixteen minutes, and a
thargic hedgehog for 22½ minutes: and neither of the animals
ppeared injured by the experiment (lxxiii. vol ii. p. 771).

CHAPTER VII.

ANIMAL HEAT.

INTIMATELY associated with the process of respiration are the production of animal heat, and the maintenance of a uniform temperature of the body; conditions as essential to the continuance of life, in warm-blooded animals, as the extrication of carbonic acid and the absorption of oxygen are.

The average temperature of the human body, in those internal parts which are most easily accessible, such as the mouth and rectum, may be estimated at from 98° to 100° F. In children, the temperature is commonly as high as 102° F. In old persons, it is about the same as in adults (Davy, xliii. 1844). Of the external parts of the body the temperature becomes lower the further they are removed from the centre of the body; thus, in the human subject, a thermometer placed in the axilla was found by Dr. John Davy to stand at 98° F., at the loins it indicated a temperature of 96½°, on the thigh 94°, on the leg 93° or 91°, on the sole of the

foot 90° (xliii. 1844). In disease, the temperature of the body may deviate several degrees above and below the average of health. In some diseases, as scarlatina and typhus, it rises as high as 106° or 107° F.; and in children, M. Roger has observed the temperature of the skin to be raised to 108.5° Fah. (cxxii. 1844). In the *morbus cæruleus*, in which there is defective arterialization of the blood from malformation of the heart, the temperature of the body is often as low as 79° or 77½°; in the Asiatic cholera, a thermometer placed in the mouth sometimes rises only to 77° or 79°. M. Roger observed the temperature of the body in children to be sometimes reduced in disease to 74.3.

The temperature of the body, in health, is about 1½° F. lower during sleep than while awake. According to Dr. Davy (cxxiii. June 1845), it is highest in the morning after rising from sleep, continues high but fluctuating till evening, and is lowest about midnight. Sustained mental exertion elevates it slightly; continued bodily exercise does so to a considerable extent; after feeding also it is somewhat raised. All these facts are important, both as showing variations in the temperature of the body correspondent with those in the production of carbonic acid in the same circumstances, and as proving that the influence which slight changes in the organic economy of warm-blooded animals have is as great or greater than that exercised by even extreme variation in the external temperature to which they are exposed. For in warm climates, Dr. Davy found the temperature of the interior of the body only from 2.7° to 3.6° F. higher than in temperate climates; and during the voyage of the "Bonite," the French naturalists, who had an opportunity of observing the influence of various climates on the same persons, found that the temperature of the human body rises and falls in only a slight degree, even in extremes of external temperatures; that it falls slowly in passing from hot to cold climates, and rises more rapidly in returning towards the torrid zone: but that these changes in the temperature of the body are more considerable in some individuals than in others (xviii. 1838, p. 456).

The temperature maintained by Mammalia, in an active state of life, according to the tables of Tiedemann and Rudolphi, averages 101°. The extremes recorded by them were 96° and 106°, the former in the narwhal, the latter in a bat (Vespertilio Pipistrella). In birds, the average is as high as 107°; the highest temperature, 111.25°, being in the small species, the linnets, &c. (cxxv. p. 234). Among reptiles, Dr. John Davy found that while the medium they were in was 75°, their average temperature was 82.5°. As a general rule, their temperature, though it falls with that of the surrounding medium, is, in temperate media, two or more degrees higher; and though it rises also with that of the medium, yet at

very high degrees ceases to do so, and remains even lower than that of the medium. Fish, insects, and other Invertebrata present, as a general rule, the same temperature as the medium in which they live, whether that be high or low; only, among fish, the tunny-tribe, with strong hearts, and red meat-like muscles, and more blood than the average of fish have, are generally 7° warmer than the water around them.

The difference, therefore, between what are commonly called the warm- and the cold-blooded animals, is not one of absolutely higher or lower temperature; for the animals, which to us, in a temperate climate, feel cold (being, like the air or water, colder than the surfaces of our bodies), would, in an external temperature of 100° or 200°,[1] have nearly the same temperature, and feel hot to us. The real difference is, as Mr. Hunter expressed it (i. vol. iii. p. 16, and vol. iv. p. 131, *et seq.*), that what we call warm-blooded animals (birds and Mammalia), have a certain "permanent heat in all atmospheres," while the temperature of the others, which we call cold-blooded, is "variable with every atmosphere."

The power of maintaining an uniform temperature, which Mammalia and birds possess, is combined with the want of power to endure such changes of temperature as are harmless to the other classes; and when their power of resisting change of temperature ceases, they suffer serious disturbances or die. M. Magendie has shown that birds and rabbits die, when, being exposed to great external heat, their temperature is raised as much as 9° above the natural standard; but they bear a reduction of the temperature of the interior of the body to a much greater amount before very dangerous or fatal consequences ensue (cxciii. 1850).

In all the ordinary circumstances of life, the maintenance of uniform temperature is effected by the production of heat sufficient to compensate for that which is constantly lost in radiation into the medium in which we live, or in combination with the fluids evaporating from the exposed surfaces of the body.

The losses thus sustained are extremely various in different circumstances; and the degrees of power which animals possess of adapting themselves to such differences are equally various. Some live best in cold regions, where they produce abundant heat for radiation, and cannot endure the heat of warm climates, where the heat that they habitually produce would, probably, be excessive, and by its continual, though perhaps small, excess, would generate disease; others, naturally inhabiting warm climates, die if removed to cold ones, as if because their power of producing heat were not quite sufficient to compensate for the constantly larger abstractions

[1] Humboldt and Bonpland saw fish thrown up from volcanoes alive, and apparently in health, along with water and vapor which raised the thermometer to 210°.

of it by radiation. Man, with the aid of intellect for the provision of artificial clothing, and with command over food, is, in these respects, superior to all other creatures; possessing the greatest power of adaptation to external temperature, and being capable of enduring extreme degrees of heat as well as of cold without injury to health. His power of adaptation is sufficient for the maintenance of an uniform temperature in a range of upwards of 200° Fahrenheit; a power which is only shared by some of the domestic animals who are his companions in his various abodes.

Sources and Mode of Production of Heat in the Body.

To explain the production of heat in the body, several theories have been advanced; but it now appears almost certain that the correct one is that which refers the generation of heat, primarily and in general, to certain chemical processes going on in the system; but admits, at the same time, that as these chemical changes are carried on in parts whose functions are, to a certain extent, under the influence of the nervous system, therefore the production of heat is liable to be modified, either locally or in every part, by the operation of that system.

In explaining the chemical changes effected in the process of respiration (p. 139), it was stated that the oxygen of the atmosphere taken into the blood is, most probably, combined in the systemic capillary vessels with the carbon and the hydrogen of disintegrated and absorbed tissues, and certain elements of food which have not been converted into tissues. That such a combination, between the oxygen of the atmosphere and the carbon and hydrogen in the blood, is continually taking place, is made nearly certain by the fact that a larger amount of carbon and hydrogen is constantly being added to the blood from the food than is required for the ordinary purposes of nutrition, and that a quantity of oxygen is also constantly being absorbed from the air in the lungs, of the disposal of which no account can be given except by regarding it as combining, for the most part, with the excess of carbon and hydrogen, and being evaporated in the form of carbonic acid and water. In other words, the blood of warm-blooded animals appears to be always receiving from the digestive canal and the lungs more carbon, hydrogen and oxygen, than are consumed in the repair of the tissues; and to be always emitting carbonic acid and water, for which no other source can be ascribed than the combination of these elements. In the processes of such combination, heat must be continually produced in the animal body. The same amount of heat will be evolved in the union of any given quantities of carbon and oxygen, and of hydrogen and oxygen, whether the combination be rapid and evident, as in ordinary combustion; or slow and imperceptible, as in the changes which are believed to occur in

the living body. And since the heat thus arising will be generated wherever the blood is carried, every part of the body will be heated equally; or so nearly equally that the rapid circulation of the blood will quickly remove any diversities of temperature in different parts.

To establish this theory, it needs to be shown that the quantity of carbon and hydrogen which, in a given time, unites in the body with oxygen, is sufficient to account for the amount of heat generated in the animal within the same time: an amount capable of maintaining the temperature of the body at from 98° to 100°, notwithstanding a large loss by radiation and evaporation.[1]

An attempt to determine this point was made by Dulong and Despretz. Dulong introduced different mammiferous animals, carnivorous as well as herbivorous, into a receiver, in which the changes produced in the air by respiration, and the volume of the different products, could be determined at the same time that the amount of heat lost by the animal could be ascertained. His experiments led him to conclude, among other points, that supposing all the oxygen, absorbed into the blood from the air in the lungs, were combined with carbon and hydrogen in the system, and that as much heat were thus generated as would be developed during the quick combustion of equal quantities of oxygen and carbon, and of oxygen and hydrogen, still, the whole quantity of heat produced would amount to only from 3-4ths to 4-5ths of that which is developed during the same space of time by carnivorous as well as herbivorous animals. Despretz placed animals in a vessel surrounded with water; an uninterrupted current of air to and from the vessel was maintained, and the volume and composition of the air employed were ascertained both before and after the experiment (which was continued 1½ or two hours), as well as the increase in the temperature of the surrounding water during it: by this means it was found that the heat which should have been generated, according to the chemical theory of respiration, would account for from 0.76 to 0.91 only of that which the animals really gave out during the same time. The failure of these experiments to account for all the heat produced, threw doubts on the chemical theory of animal heat (as the proposed explanation has been called), till Liebig lately showed that Dulong and Despretz were in error in their conclusions, from having formed too low an estimate of the heat produced in the combustion of carbon and hydrogen. On repeating their experiments, and using the more accurate numbers to represent these *com-*

[1] Some heat will also be generated in the combination of sulphur and phosphorus with oxygen, to which reference has been made (p. 136): but the amount thus produced has not been estimated, and need not be considered in the exposition of a theory which can, at present, be stated in only the most general terms.

bustion-heats, Liebig finds reason to believe that the quantity of heat which would be generated, by the union of the oxygen absorbed into the blood from the atmosphere with the carbon and hydrogen taken into the system as food, is sufficient to account for the whole of the caloric formed in the animal body.[1]

Many things observed in the economy and habits of animals are explicable by this theory, and are, therefore, evidence for its truth. Thus, as a general rule, in the various classes of animals, as well as in individual examples of each class, the quantity of heat generated in the body is in direct proportion to the activity of the respiratory process. The highest animal temperature, for example, is found in birds, in whom the function of respiration is most actively performed; in Mammalia, the process of oxygenation is less active, and the average temperature of the body less, than in birds. In reptiles, both the respiration and the heat are at a much lower standard; whilst in animals below them, in which the function of respiration is at the lowest point, a power of producing heat is, in ordinary circumstances, hardly discernible. Among these lower animals, however, the observations of Mr. Newport (xliii: 1837) supply confirmatory evidence. He shows that the larva, in which the respiratory organs are smaller in comparison with the size of the body, has a lower temperature than the perfect insect. Volant insects have the highest temperature, and they have always the largest respiratory organs and breathe the greatest quantity of air: while among terrestrial insects, those also produce the most heat which have the largest respiratory organs and breathe the most air. During sleep, hybernation, and other states of inaction, respiration is slower or suspended, and the temperature is proportionally diminished; while on the other hand, when the insect is most active and respiring most voluminously, its amount of temperature is at its maximum, and corresponds with the quantity of respiration. Neither the rapidity of the circulation nor the size of the nervous system, according to Mr. Newport, presents such a constant relation to the evolution of heat.

Similar evidence in favor of this theory of animal heat is furnished by the fact that heat is sometimes evolved by plants, in a quantity which appears to be in direct proportion to the amount of oxygen they at the same time absorb and convert into carbonic acid. For example, their evolution of heat is most evident during flowering and the germination of seeds, the times at which the largest amount of carbonic acid is exhaled.

The quantity and quality of food consumed by man and animals in the different climates and seasons, also appear to be adapted to

[1] Liebig's estimates and calculations may be referred to in the Lancet (Feb. 1845).

ction of various amounts of heat by the combination of d hydrogen with oxygen. In northern regions, for ex- d in the colder seasons of more southern climes, the of food consumed is (speaking very generally) greater consumed by the same men or animals in opposite conditions te and seasons. And the food which appears naturally to the inhabitants of the coldest climates, such as the se- ty and oily substances, abounds in carbon and hydrogen, ted to combine with the large quantities of oxygen which, g cold dense air, they absorb from their lungs.

influence of the nervous system in modifying the production has been already referred to. The experiments and observ- hich best illustrate it are those showing, first, that when ply of nervous influence to a part is cut off, the temperature part falls below its ordinary degree; and, secondly, that eath is caused by severe injury to or removal of the nervous , the temperature of the body rapidly falls, even though al respiration be performed, the circulation maintained, and ppearance the ordinary chemical changes of the body be com- effected. It has been repeatedly noticed that, after division nerves of a limb, its temperature falls : and this diminution t has been remarked still more plainly in limbs deprived of s influence by paralysis. For example, Mr. Earle (xli. vol. 173) found the temperature of the hand of a paralyzed arm 70°, while that of the sound side had a temperature of 92° F. ctrifying the paralyzed limb, the temperature rose to 77°. In r case, the temperature of the paralyzed finger was 56° F., that of the unaffected hand was 62°. Sir B. C. Brodie (xliii. nd 1812) found, that if artificial respiration was kept up in s killed by decapitation, division of the medulla oblongata, ction of the brain, or poisoning with Woorara poison, the action heart continued, and the blood underwent the usual changes in ngs, as shown by the analysis of the air respired, but that the f the body was not maintained : on the contrary, being cooled air forced into the lungs, it became cold more rapidly than dy of an animal in which artificial respiration was not kept up. equal certainty, though less definitely, the influence of the s system on the production of heat is shown in the rapid and ntary increase of temperature, sometimes general, at other quite local, which is observed in states of nervous excitement ; general increase of warmth of the body, sometimes amounting spiration, which is excited by passions of the mind ; in the rush of heat to the face, which is not a mere sensation; and equally rapid diminution of temperature in the depressing s. But none of these instances suffices to prove that heat is

gener[illegible]n ere nervous action, independent of any chemical chang[illegible]s well explicable on the supposition that the influence o[illegible]ous system alters in some way, the chemical processes [illegible]ch the heat is commonly generated. There are ample [illegible]t the nervous system, especially in the most highly organized animals, does so modify all the functions of organic life; and it appears more reasonable to suppose that it thus influences the production of heat, th[illegible]t to any more direct agency.

[According to the rec[illegible] of M. Cl. Bernard,[1] it appears that an elevation [illegible] constantly takes place on one side of the face, whe[illegible]hich unites the Sympathetic ganglia of the neck on th[illegible]hrough; this increase being not only perceptible to th[illegible]showing itself by a thermometer introduced into [illegible]ears, even to the extent of from 7° to 11° Fal[illegible]rior cervical ganglion is removed, the same ef[illegible]t with yet greater intensity. This difference is maintained for many months, and is not connected with the occurrence of inflammation, congestion, œdema, or any other pathological change in the part; moreover, it is not prevented from manifesting itself by the division of any of the cerebro-spinal nerves of the face. It is remarkable that the sensibility of the parts thus affected should be no less augmented than their temperature.

Dr. Brown-Sequard has observed the same remarkable phenomena as those detailed by M. Cl. Bernard, but he regards them as mere results of the paralysis, and of the consequent dilatation of the bloodvessels. In consequence of this dilatation, the blood reaches the part supplied by the nerve in larger quantities; the nutrition is therefore more active. The increased sensibility is a result of the augmented vital properties of the nerves when their nutrition is increased. Dr. Brown-Sequard has likewise noticed the increase of temperature of the ear over that of the rectum, to the amount of one or two degrees Fahr.; but it must be remembered that the temperature of the rectum is a little lower than that of the blood, and as the ear is gorged with that fluid, it is easy to understand why it should possess its temperature. Many facts prove that the degree of temperature and sensibility in a part are in direct ratio with the amount of blood circulating in it.

If galvanism be applied to the superior portion of the sympathetic nerve after it has been cut in the neck, the vessels of the face and ear, after a short time, begin to contract, and subsequently resume their normal condition, if they do not even diminish. Coincidently with this diminution, there is a decrease of the temperature and sensibility of the face and ear, until the palsied and sound side are alike in this respect.

[1] Gazette Médicale, Fevr. 21, 1852.

n the galvanic current ceases to act, the vessels again dilate, the phenomena discovered by M. Bernard reappear. It ppears that the only direct effect of section of the cervical of the sympathetic is the paralysis and consequent dilatation loodvessels. Another deduction from these experiments is, sympathetic sends motor fibres to many of the bloodvessels ead.[1]]

ne foregoing pages, the illustrations of the power of main- an uniform temperature have had reference to the ordinary man living in a medium colder than his body, and therefore heat both by radiation and evaporation. The losses in these ys will bear, in general, an inverse proportion to one another; all loss of heat in evaporation in cold climates may go far pensate for the greater loss by radiation; as, on the other the great amount of fluid evaporated in hot air may remove as much heat as is commonly lost by both radiation and ation in ordinary temperatures. Thus, it is possible that antities of heat required for the maintenance of an uniform temperature in various climates and seasons are not so dif- as they may, at first thought, seem: but on these points no ite information has been yet obtained.[2]

ther, as to the maintenance of the temperature of the body t air is more known than that great heat can for a time be with little change in the proper temperature of the body, led the air be dry. Sir Charles Blagden and others supported perature varying between 198° and 211° F. in dry air for l minutes; and in a subsequent experiment he remained eight tes in a temperature of 260°. Delaroche and Berger (cxxxii.) red that the temperature of rabbits was raised only a few de- when they were exposed to heat varying from 122° to 194°. uch heats are not tolerable when the air is moist as well as o as to prevent evaporation from the body. M. C. James April, 1844) states that, in the vapor baths of Nero, he was t suffocated in a temperature of 112°, while in the caves of ccio, in which the air is dry, he was but little discomfited by perature of 176°. In the former, evaporation from the skin mpossible; in the latter, it was probably abundant, and the of vapor which would rise from all the surface of the body

[1] *Vide* Phil. Med. Exam., N. S., vol. viii. No. viii. August, 1852.

[2] Crichton has made estimates of the heat given out, per minute, from ngs in warming the inspired air, and in combination with the evapo- rater: it would be enough to heat (at the most) 96.34 grains of water 2° to 212° (ex. p. 236). At this rate, the loss by evaporation from n and lungs together may be roughly estimated at enough to heat 4000 grains of water from 32° to 212°.

would, by its very slowly conducting power, defend it for a time from the full action of the external heat.

It remains to notice certain conditions by which the production of heat is modified.

The *effects of age* are noticeable. M. Edwards found the power of generating heat to be less in old people; and the same was observed by Dr. Davy (xliii. 1844); who, in eight people, between eighty-seven and ninety-five years old, found that, although the average temperature of the body was not lower than that of younger persons, yet the power of resisting cold was less in them—exposure to a low temperature causing a greater reduction of heat than in young persons.

The same rapid diminution of temperature was observed by M. Edwards in the new-born young of most carnivorous and rodent animals when they were removed from the parent, the temperature of the atmosphere being between 50° and 53½° F.; whereas, while lying close to the body of the mother, their temperature was only 2 or 3 degrees lower than hers. The same law applies to the young of birds. Young sparrows, a week after they were hatched, had a temperature of 95° to 97°, while in the nest; but when taken from it, their temperature fell in one hour to 66½°, the temperature of the atmosphere being at the time 62½°. It appears from his investigations that, in respect of the power of generating heat, some Mammalia are born in a less developed condition than others; and that the young of dogs, cats, and rabbits, for example, are inferior to the young of those animals which are not born blind. The need of external warmth to keep up the temperature of new-born children is well known; the researches of M. Edwards show that the want of it is, as Hunter suggested, a much more frequent cause of death in new-born children than is generally supposed, and furnish a strong argument against the idea that children, by early exposure to cold, can soon be hardened into resisting its injurious influence.

Active exercise, as already stated, raises the temperature of the body. This may be partly ascribed to the fact that every muscular contraction is attended by the development of one or two degrees of heat in the acting muscle; and that the heat is increased according to the number and rapidity of these contractions, and may be quickly diffused by the blood circulating from the heated muscles. Possibly, also, some heat may be generated in the various movements, stretchings, and recoilings of the other tissues, as the arteries, whose elastic walls, alternately dilated and contracted, may give out some heat, just as caoutchouc, alternately stretched and recoiling, becomes hot. But the heat thus developed cannot be so much as some have supposed. (Winn, xvii. Ser. 3, vol. xiv. p. 174; Winter, xxx. 1843, p. 794.)

The *influence of external coverings* for the body must not be unnoticed. In warm-blooded animals they are always adapted, among many purposes, to the maintenance of uniform temperature; and man adapts for himself such as are, for the same purpose, fitted to the various climates to which he is exposed.

By their means, and by his command over food and fire, perhaps as much as by his capacity of developing appropriate amounts of heat, he maintains his temperature on all accessible parts of the surface of the earth.

CHAPTER VIII.

DIGESTION.

DIGESTION is the process by which those parts of our food which may be employed in the formation and repair of the tissues, or in the production of heat, are made fit to be absorbed and added to the blood.

Food may be considered in its relation to the two purposes above mentioned; and the various articles of food may be artificially classified according as they are chiefly subservient to one or the other of these purposes. All articles of food that are to be employed in the production of heat, must contain a larger proportion of carbon and hydrogen than is sufficient to form water with the oxygen that they contain; and none are appropriate for the maintenance of any tissues (except the adipose) unless they contain nitrogen, and are capable of conversion into the nitrogenous principles of the blood.

The name of *nutritive* or *plastic* is given to those principles of food which admit of conversion into the albumen or fibrine of the blood, and of being subsequently assimilated, through the medium of the blood, by the tissues. And those principles, comprising the greater part of the non-nitrogenous materials of food, in the form of fat, starch, sugar, gum, and other similar substances, which are believed to be employed in the production of heat, are named *calorificient*, or sometimes *respiratory* food.

An easier division of foods than this, according to their destination, is derived from their origins; for all consist of either animal or vegetable substances. No substance can afford nutriment, even though it contain all the elements of organic bodies, unless it have all the natural peculiarities of organic composition, and contain, incorporated with its other elements, some of those derived from the mineral kingdom, which, as *incidental elements* (p. 14), are

found in the organized tissues; such as sulphur, iron, lime, magnesia, &c.

Man is supported as well by food constituted wholly of animal substances, as by that which is formed entirely of vegetable matters; and the structure of his teeth, as well as experience, seems to point out that he is destined for a mixed kind of aliment. In the case of carnivorous animals, the food upon which they exist, consisting as it does of the flesh [illegible] of other animals, not only contains all the elements of [illegible]ir own blood and tissues are composed, but contains th[illegible]ed, probably, in the same forms. Therefore, little m[illegible]m requisite, in the preparation of this kind of food fo[illegible]ition of the body, than that it should be dissolved and con[illegible]nto the blood in a condition capable of being reorgan[illegible] the case of the herbivorous animals, which feed exch[illegible]egetable substances, it might seem as if there would b[illegible]ulty in procuring food capable of assimilation into their blood and tissues. But the chief ordinary articles of vegetable food contain substances identical, in composition, with the albumen, fibrine, and caseine, which constitute the principal nutritive materials in animal food. Albumen is abundant in the juices and seeds of nearly all vegetables; the gluten which exists, especially in corn, and other seeds of grasses, as well as in their juices, is identical in composition with fibrine, and is now commonly named vegetable fibrine; and the substance named legumin, which is obtained especially from peas, beans, and other seeds of leguminous plants, and from the potato, is identical with the caseine of milk. All these vegetable substances are, equally with the corresponding animal principles, and in the same manner, capable of conversion into blood and tissues; and, like the blood and tissues in both classes of animals, the nitrogenous food of both may be regarded as in all essential respects similar.

An apparently more considerable difference between animal and vegetable food consists in the different kind, and proportionately larger quantity, of the non-nitrogenous principles contained in the latter. The only non-nitrogenous organic substances in animal food are furnished by the fat, and, in some instances, by the vegetable matters that may chance to be in the digestive canals of such animals as are eaten whole. The amount of these is far less than that of the non-nitrogenous substances consumed by herbivorous animals, in their quantities of starch, sugar, gum, oil, and other ternary compounds. Yet, that the final destination of the ternary principles is the same in both classes, is almost proved by the ability of man and many other animals to subsist, and, apparently, to maintain an identical composition and an uniform temperature, with food of either kind.

Again, the several alimentary substances, from both animal and

vegetable substances, may be arranged, according to the system of Dr. Prout, in three classes, under the names of *albuminous*, *saccharine*, and *oleaginous* principles. In the albuminous group, are included all the nitrogenous principles, whether derived from the animal or from the vegetable kingdom. These comprise albumen, fibrine, caseine, gelatine, and chondrine; the two latter substances being classed under this head on account of their bearing a closer resemblance to the albuminous than to any other principles of food. The *saccharine* group comprises substances derived exclusively from the vegetable kingdom, viz., sugar itself, and the various principles capable of being converted into it, as starch, gum, pectine, and lignine, or woody fibre: all of which are composed of carbon, hydrogen, and oxygen, with the two latter in the proportion in which they form water. The *oleaginous* group includes the various kinds of fatty and oily principles, which occur abundantly in both the animal and vegetable kingdoms. All are composed principally of carbon and hydrogen: the quantity of the former element usually exceeding that of the latter; and both being more than sufficient to form water with the oxygen they contain. Besides these three principal divisions, Dr. Prout makes a fourth division for the *aqueous* part of food. For, besides that water constitutes nearly four-fifths of the total weight of the animal body, and must, therefore, enter largely into the composition of food, it is highly probable that it plays an important part in the various transformations undergone in the system, and thus contributes materially to the nutrition of the different textures.

It has been already said that animals cannot subsist on any but organic substances, and that these must contain the incidental elements and compounds which are naturally combined with them; in other words, not even organic compounds are nutritive unless they are supplied in their natural state. The most singular instance of this fact is, perhaps, that of the production of scurvy by the want of vegetable food, and its cure by giving vegetables; which, however, must be either raw, or simply preserved, or so cooked that their saline constituents may not be removed from them. Pure fibrine, pure gelatine, and other principles purified from the substances naturally mingled with them, are incapable of supporting life for more than a brief time.

Moreover, health cannot be maintained by any number of substances derived exclusively from one of the three groups of alimentary principles. A mixture of nitrogenous and non-nitrogenous substances, together with the inorganic principles which are severally contained in them, is essential to the well-being, and, generally, even to the existence of an animal. The truth of this is demonstrated by experiments performed for the purpose, and is illustrated by the composition of the food prepared by nature as the exclusive

source of nourishment to the young of Mammalia, namely, milk. In milk, the albuminous group of aliments is represented by the caseine, the oleaginous by the butter, the aqueous by the water, the saccharine by the sugar of milk.[1] Milk, likewise, contains phosphate of lime, alkaline and other salts, and a trace of iron; so that it may be briefly said to include all the substances which the tissues of the growing animal need for their nutrition, and which are required for the production of animal heat. The yelk and albumen of eggs are in the same relation, as food for the embryos of oviparous animals, as milk is to the young of Mammalia, and afford another example of mixed food being provided as the most perfect for nutrition.

The experiments illustrating the same principle have been chiefly performed by Magendie (cxxxiii.). Dogs were fed exclusively on sugar and distilled water. During the first seven or eight days they were brisk and active, and took their food and drink as usual; but in the course of the second week they began to get thin, although their appetite continued good, and they took daily between six and eight ounces of sugar. The emaciation increased during the third week, and they became feeble, and lost their activity and appetite. At the same time an ulcer formed on each cornea, followed by an escape of the humors of the eye; this took place in repeated experiments. The animals still continued to eat three or four ounces of sugar daily; but became at length so feeble as to be incapable of motion, and died on a day varying from the 31st to the 34th. On dissection, their bodies presented all the appearances produced by death from starvation; indeed, dogs will live almost the same length of time without any food at all.

When dogs were fed exclusively on gum, results almost similar to the above ensued. When they were kept on olive-oil and water, all the phenomena produced were the same, except that no ulceration of the cornea took place: the effects were also the same with butter. Tiedemann and Gmelin obtained very similar results. They fed different geese, one with sugar and water, another with gum and water, and a third with starch and water. All gradually lost weight. The one fed with gum died on the sixteenth day; that fed with sugar on the twenty-second; the third, which was fed with starch, on the twenty-fourth, and another on the twenty-seventh day; having lost, during these periods, from one-sixth to one-half of their weight. The experiments of Chossat (xix. Oct. 1843) and Letellier (xii. 1844) prove the same; and in men, the

[1] At least it is so in the milk of herbivorous animals; but, according to Dumas (xix. Oct. 1845), sugar does not exist in the milk of Carnivora, except when some saccharine or farinaceous principle is mixed with their food; its place in their natural milk is filled, as it is in their food, by the fatty matter.

ame is shown by the various diseases to which they who consume at little nitrogenous food are liable, and especially, as Dr. Budd as shown, by the affection of the cornea which is observed in lindoos feeding almost exclusively on rice. But it is not only the on-nitrogenous substances, which, taken alone, are insufficient for he maintenance of health. The experiments of the Academies of rance and Amsterdam were equally conclusive that gelatine alone oon ceases to be nutritive (xxv. 1843–4, p. 35).

These facts prove the necessity of a mixture of elementary rinciples in the food; and, beyond this, Magendie's further ex-eriments appear to prove that animals cannot live long if fed xclusively on any single article of food (except milk), even al-hough it contains principles belonging to each of the three groups f alimentary substances. For example (to mention only some of is results), a dog fed on white bread, wheat, and water, did not ive more than fifty days; rabbits and guinea-pigs fed on any one f the following substances—wheat, oats, barley, cabbage, or car-ots—died with all the signs of inanition in fifteen days; while, if he same substances were given simultaneously, or in succession, he animals suffered no ill effect.

Changes of the Food effected in the Mouth.

The first of the series of changes to which the food is subjected n the digestive canal takes place in the cavity of the mouth; the olid articles of food are here submitted to the action of the teeth, hereby they are divided and crushed, and by being at the same ime mixed with the fluids of the mouth, are reduced to a soft pulp apable of being easily swallowed. The fluids with which the food is mixed in the mouth consist of the secretion of the salivary glands nd the mucus secreted by the lining membrane of the whole buc-al cavity.

The glands concerned in the production of *saliva* are very exten-ive, and, in man and Mammalia generally, are presented in the form of four pairs of large glands, the parotid, submaxillary, sub-lingual, and intralingual, and numerous smaller bodies, of similar structure and with separate ducts, which are scattered thickly be-neath the mucous membrane of the lips, cheeks, soft palate, and root of the tongue. These all have the structure common to what are termed conglomerate glands, which will be spoken of in the chapter on SECRETION. Saliva, as it commonly flows from the mouth, is mixed with the secretion of the mucous membrane, and often with air-bubbles, which, being retained by its viscidity, make it frothy.

When obtained from the parotid ducts, and free from mucus, aliva is a transparent watery fluid, the specific gravity of which aries from 1.006 to 1.009, and in which, when examined with

the microscope, are found floating a number of minute particles, derived from the secreting ducts and vesicles of the glands. In the impure or mixed saliva are found, besides these particles, numerous epithelial scales separated from the surface of the mucous membrane of the mouth and tongue, and mucous corpuscles, discharged for[illegible]e most part from the tonsils, which, when the saliva is c[illegible] in a deep vessel, and left at rest, subside in the form of a [illegible] the supernatant salivary fluid transparen[illegible] a pale bluish-gray tint. In *reaction*, the [illegible]ted, appears to be always alkaline; and that [illegible] is said to be more strongly alkaline than th[illegible]ary glands. This alkaline condition is most evide[illegible]n is going on, and, according to Dr. Wright (: [illegible] degree of alkalinity of the saliva bears a direct [illegible] acidity of the gastric fluid secreted at the same [illegible]sting, the saliva, although secreted alkaline, shortly becomes [illegible]; and it does so especially when secreted slowly, and allowed to mix with the acid mucus of the mouth, by which its alkaline reaction is destroyed.

According to Dr. Wright (xxx. March, 1842), whose analysis does not materially differ from the more recent analyses of Frerichs (lix. 1850, p. 136), and others, the *composition of saliva* is—

Water . . .	988.1	Mucus . . .	2.6
Ptyaline . . .	1.8	Ashes . . .	4.1
Fatty matter . .	.5	Loss . . .	1.2
Albumen (with soda) .	1.7		1000.0

Ptyaline is the name given to a supposed peculiar animal matter, which is insoluble in alcohol. By Mialhe, it is stated to be closely analogous to the vegetable substance, termed diastase; but it is more commonly regarded as belonging to the ill-defined class of extractive matters.

The ashes of saliva have been analyzed by Enderlin (x. 1844), who found that they consist of substances very similar to those in the ashes of blood, and believes that the alkalinity of the saliva, like that of the blood, is due to the tribasic phosphate of soda. The other salts which he found in it were chlorides of sodium and potassium, sulphate of soda, and phosphates of lime, magnesia, and of iron. Saliva is also said to contain a small quantity of sulpho-cyanogen: the presence of which is indicated by a deep red color when saliva is mixed with a neutral solution of a salt of the peroxide of iron. See, on the question, Pettenkofer (lix. 1846, p. 115) and Strahl (lix. 1847, p. 100). The tartar which collects on the human teeth consists almost entirely of the earthy phosphates, combined with about 19 per cent. of animal matter, and containing shells of infusoria, and other accidental mixtures.

The rate at which saliva is secreted is subject to considerable

riation. When the tongue and muscles concerned in mastication e at rest, and the nerves of the mouth are subject to no unusual imulus, the quantity secreted is not more than sufficient, with the ucus, to keep the mouth moist. But the flow is much accelerated hen the movements of mastication take place, and especially when ey are combined with the presence of food in the mouth. It may e excited, also, even when the mouth is at rest, by the mental im-ressions produced by the sight or thought of food. Under these arying circumstances, the *quantity* of saliva secreted in twenty-our hours varies also; its average amount probably ranges from fteen to twenty ounces. In a man who had a fistulous opening of he parotid duct, Mitscherlich found that the quantity of saliva lischarged from it during twenty-four hours, was from two to three unces; and the saliva collected from the mouth during the same eriod, and derived from the other salivary glands, amounted to ix times more than that from the one parotid.

The *purposes served by saliva* are of several kinds. In the first place, acting mechanically, it keeps the mouth in a due condition of moisture, facilitating the movements of the tongue in speaking, and the mastication of food. Thus also it serves in dissolving sapid substances, and rendering them capable of exciting the nerves of taste. But the principal mechanical purpose of the saliva is that, by mixing with the food during mastication, it makes it a soft pulpy mass, such as may be easily swallowed. To this purpose the saliva is adapted both by quantity and quality. For, speaking generally, the quantity secreted during feeding is in direct proportion to the dryness and hardness of the food: as M. Lassaigne has shown, by a table of the quantity produced in the mastication of a hundred parts of each of several kinds of food: thirty parts suffice for a hundred parts of crumb of bread, but not less than 120 for the crusts; 42.5 parts of saliva are produced for the hundred of roast meat; 3.7 for as much of apples; and so on, according to the general rule above stated. The quality of saliva is equally adapted to this end. It is easy to see how much more readily it mixes with most kinds of food than water alone does; and M. Bernard believes, from his experiments, that the saliva from the parotid, labial, and other small glands, being more aqueous than the rest, is that which is chiefly *braided* and mixed with the food in mastication; while the more viscid mucoid secretion of the submaxillary, palatine, and tonsillitic glands, is spread over the surface of the softened mass to enable it to slide more easily through the fauces and œsophagus.

Beyond these, its mechanical purposes, there are reasons for supposing that saliva performs some chemical part in the digestion of the food. The chief of these reasons are, the number and size of the glands engaged in the secretion; the variety of substances

which enter into its composition, and which can scarcely be supposed to be of use so far as its mechanical properties are concerned; the quantity which is secreted, not only during mastication, but after the food has passed into the stomach, especially in old persons, who, from their loss of teeth, frequently swallow their food in an imperfectly masticated state; the fact that the saliva secreted during digestion is more alkaline than at other times; and, lastly, the results of certain experiments.

Among the experiments are those of Spallanzani and Reaumur, who found that food inclosed in perforated tubes, and introduced into the stomach of an animal, was more quickly digested when it had been previously impregnated with saliva than when it was moistened with water. Dr. Wright, also, found that if the œsophagus of a dog is tied, and food mixed with water alone is placed in the stomach, the food will remain undigested though the stomach may secrete abundant acid fluid; but if the same food were mixed with saliva, and the rest of the experiment similarly performed, the food was readily digested.

But although it may hence appear that the saliva has more than a mechanical influence in promoting digestion, yet the nature of the chemical part it takes is uncertain. Its composition, as traced by chemical analysis, offers no guide. Its alkalinity, though, as already stated, it appears to increase in the same proportion as the acidity of the secretion of the stomach both in health and disease, is never sufficient to neutralize the gastric fluid; the contents of the stomach, including as they do the saliva swallowed, are always acid. The very short time during which the saliva remains in contact with the food before it is neutralized by the acid of the stomach, precludes the notion that the alkali is the principal constituent by which it assists in digestion. Its organic principles may, however, have more power; for numerous experiments, easily repeated, show that when saliva or a portion of salivary gland is added to starch-paste, the starch is quickly transformed into dextrine, and grape-sugar; and when common raw starch is masticated and mingled with saliva, and kept with it at a temperature of 90° or 100°, the starch-grains are cracked or eroded, and their contents are transformed in the same manner as the starch-paste.[1] Changes similar to these are effected on the starch of farinaceous food (especially after cooking) in the stomach; and it is reasonable to refer them to the action of the saliva, because the acid of the gastric fluid tends to retard or prevent, rather than favor, the transformation of

[1] See on these points Leuchs (xxxii. p. 577), Mialhe (xii. 1845), Wright (xxx. 1842–3), Lehmann (xiv. 1843,) a report of the Academy of Sciences, translated in the Medical Gazette, vol. xxxvii. p. 788, and Valentin's summary in Canstatt's Jahresberichte for 1850, p. 131.

the starch. It may therefore be held that a purpose served by the saliva in the digestive process is that of assisting in the transformation of the starch, which enters so largely into the composition of most articles of vegetable food, and which (being naturally insoluble) is converted into the soluble dextrine or grape-sugar, and made fit for absorption.

It appears from the experiments of Magendie (xviii. July, 1846) and Bernard (lix. 1847, p. 117) that many substances besides saliva may excite this transformation of starch, such as pieces of the mucous membrane of the mouth, bladder, rectum, and other parts, various animal and vegetable tissues, and even morbid products; but the gastric fluid will not produce the same effect. The property, therefore, cannot be assigned to any peculiar organic principle in the saliva. The part of the saliva which appears most active is that secreted by the small glands and the mucous membrane of the mouth. (Bernard, l. c. Magendie, exc. Oct. 1839, p. 546; see also Frerichs, lix. 1850, p. 134.) If the influence of saliva in assisting the digestion of farinaceous food be admitted, and the tendency of all the recent observations on the subject is in favor of this view, we have yet to seek for the corresponding purpose served by the saliva of Carnivora who consume no such food; for on this point there is at present but little information. It is, indeed, unknown whether saliva exercises any kind of digestive power over animal substances; no such power has been clearly shown by any of the numerous experiments intended to display it.[1]

PASSAGE OF FOOD INTO THE STOMACH.

When properly masticated, the food is transmitted in successive portions to the stomach by the act of *deglutition* or *swallowing*. This act, for the purpose of description, may be divided into three parts. In the first, particles of food collected to a morsel glide between the surface of the tongue and the palatine arch, till they have passed the anterior arch of the fauces; in the second, the morsel is carried through the pharynx; and in the third, it reaches the stomach through the œsophagus. These three acts follow each other rapidly. The first is performed voluntarily by the muscles of the tongue and cheeks. The second also is effected with the aid of muscles which are in part endued with voluntary motion, such

[1] On the action of Saliva, as well as on other points connected with the process of digestion, the student will find much valuable information in the instructive lectures by Dr. Bence Jones, now publishing in the Medical Times. [See also Amer. Journ. of Med. Sciences, Oct. 1851, for a *resumé* of M. C. Bernard's experiments. Also Carpenter's Human Physiology, pp. 527, 8, *et seq.*]

as the m the soft palate and pharynx; but it is, nevertheless, an involuntary act, and takes place without our being able to prevent it, as the morsel of food, drink, or saliva is carried backwards to a certain point of the tongue's surface. When we appear to swallow voluntarily, we only convey, through the first act of deglutition, a portion of food or saliva beyond the anterior arch of the palate; then, the substance acts as a stimulus, which, in accordance with the laws of [illegible]ts hereafter to be described, is carried by the sensiti[illegible]e medulla oblongata, where it is reflected to the [illegible]nd an involuntary adapted action of the muscl[illegible] and pharynx ensues. The third act of deglutition [illegible]he œsophagus, the muscular fibres of which are enti[illegible] influence of the will.

The second act of [illegible]e most complicated because the food must pass by [illegible]ice of the nose and the rima glottidis of the larynx, [illegible]g them. When it has been brought, by the first act, behind the anterior arches of the palate, it is moved onwards by the tongue being carried backwards, and by the muscles of the anterior arches contracting behind it. The root of the tongue being retracted, and the larynx being raised with the pharynx and carried forwards under the tongue, the epiglottis is pressed over the rima glottidis, and the morsel glides past it; the closure of the glottis being additionally secured by the simultaneous contraction of its own muscles, so that even when the epiglottis is destroyed there is little danger of food or drink passing into the larynx, so long as its muscles can act freely. At the same time, the approximation of the sides of the posterior palatine arch, which move quickly inwards like side-curtains, closes the passage into the upper part of the pharynx and the posterior nares, and forms an inclined plane, along the under surface of which the morsel descends; when the pharynx, raised up to receive it, in its turn contracts, and forces it onwards into the œsophagus.

In the third act, in which the food passes through the œsophagus, every part of that tube, as it receives the morsel, and is dilated by it, is stimulated to contract; hence an undulatory contraction of the œsophagus, which is easily observable in horses while drinking, proceeds rapidly along the tube. It is only when the morsels swallowed are large, or taken too quickly in succession, that the progressive contraction of the œsophagus is slow, and attended with pain.

Besides the actions ensuing in the œsophagus during the passage of food, certain rhythmic contractions have been observed at its lower part, independently of deglutition. They are produced by the fibres near the cardiac orifice of the stomach, which fibres are usually in a state of contraction, especially when the stomach is

tall, and appear to act as a kind of sphincter to prevent the regurgitation of food. During vomiting they are relaxed; and at the same time, the whole muscular tissue of the tube is said to perform an anti-peristaltic motion, the reverse of that which it executes during deglutition. When vomiting has been produced by the injection of tartar emetic into the veins, these anti-peristaltic motions of the œsophagus are said to be continued, even though the tube is separated from the stomach.

DIGESTION OF FOOD IN THE STOMACH.

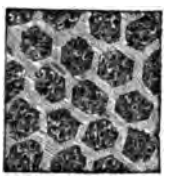
Structure of the Stomach.

It appears to be an universal character of animals, that they have an internal cavity for the production of a chemical change in the aliment—a cavity for digestion: and when this cavity is compound, the part in which the food undergoes its principal and most important changes in the stomach.

In man, and those Mammalia which are provided with a single stomach, its walls consist of three distinct layers, or coats, viz.: an external peritoneal, an internal mucous, and an intermediate muscular coat, with bloodvessels, lymphatics, and nerves distributed in and between them. In relation to the physiology of the stomach in digestion, only the muscular and mucous coats need be considered.

The *muscular coat* of the stomach consists of three separate layers, or sets of fibres, which, according to their several directions, are named the longitudinal, circular, and oblique. The *longitudinal* set are the most superficial; they are continuous with the longitudinal fibres of the œsophagus, and spread out in a diverging manner over the great end and sides of the stomach. They extend as far as the pylorus, being especially distinct at the lesser or upper curvature of the stomach, along which they pass in several strong bands. The next set are the *circular* or *transverse* fibres, which more or less completely encircle all parts of the stomach; they are most abundant at the middle, and in the pyloric portion of the organ, and some form the chief part of the thick projecting ring at the pylorus. The next, and consequently deepest set of fibres are the *oblique*; they are comparatively few in number, and are placed only at the cardiac orifice, and portion of the

Fig. 32.



Mucous membrane of the stomach, after Boyd. Cells of human stomach—open mouths of tubes seen at the bottom of each—magnified 32 diameters.

stomach, over both surfaces of which they are spread, some passing obliquely from left to right, others from right to left, around the cardiac orifice, to which, by their interlacing, they form a kind of sphincter, continuous with that round the lower end of the œsophagus.

Section of mucous membrane of the stomach near the pylorus, showing the gastric glands. 1. Magnified three times; 2. magnified twenty times.

nbrane of the stomach rests loose cellular membrane or which connects it with the contains its principal blood- d when the stomach is dis- th, level, soft, and velvety; tate it is thrown into numer- dinal folds, or rugæ. When ns, the internal or free sur- face, ccurately pointed out by Dr. Sprott Boyd (xciv. vol. xlvi.), presents a peculiar honeycomb appearance, produced by shallow, polygonal depressions or cells (fig. 32), the diameter of which varies generally from 1-200th to 1-350th of an inch; but near the pylorus is as much as 1-350th of an inch. They are separated by slightly elevated ridges, which sometimes, especially in certain morbid states of the stomach, bear minute, narrow, vascular processes that look like villi, and have given rise to the erroneous supposition that the stomach has absorbing villi like those of the small intestines. In the bottom of the cells, minute openings are visible (fig. 32), which are the orifices of perpendicular glands, imbedded side by side in sets or bundles, in the substance of the mucous membrane, and composing nearly the whole structure.

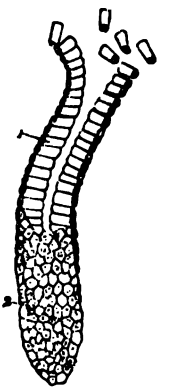
These tubular glands vary in length from one-fourth of a line to nearly a line; they are longer and more thickly set towards the pylorus than elsewhere; their length is equal to the various thickness of the mucous membrane of the stomach at different parts. At their bases, which rest on the submucous tissue, they measure about 1-300th of an inch in diameter, and at their orifices about 1-500th. Occasionally, two contiguous tubules coalesce and open on the surface of the stomach by a common orifice or duct. Over all their walls capillary bloodvessels are spread, derived from arteries whose principal trunks lie in the submucous tissue, and send up vertical branches through the interspaces between the several bundles of glands, which branches form anastomoses in the ridges

polygonal spaces on the inter-
of the stomach.

of these *gastric glands* seems
duction of cells containing the
gastric fluid. During the in-
een successive periods of diges-
he stomach is empty, the glands
e at rest; they are called into
the fresh introduction of food.

consist, essentially, of tubular
of the basement-membrane of
coat of the stomach; while
gestion they are filled with cells,
stages of development, engaged
ration of gastric fluid. In the
of these cells minute granules
e generated at the deeper part
nd; two or more of these gran-
ing together form nuclei, and
ed into nucleated cells. In the
s of the gland, those parts which
; the free surface, secondary cells
ped within these primary ones;
f the latter then appear to con-
orm the proper membrane of the
le the new generation of cells,

Fig. 34.



One of the tubular follicles of the pig's stomach, after Wasmann, cut obliquely so as to display the upper part of its cavity, with the cylindrical epithelium forming its walls. At the lower part of the follicle, the external nucleated extremities of the cylinders of epithelium are seen.

gastric fluid, are discharged and mix with the food in
h.

boration of the gastric fluid in these cells seems to be per-
y as they reach the surface, for, according to Bernard
h, 1844), the mucous membrane is not acid a little below
. When the stomach is empty and inactive, the glands
be also empty, and to have their walls lined to a greater
th, with cylindrical epithelium similar to that by which
mucous surface of the stomach is covered during the
f digestion. And the presence of this epithelium in the
ands usually closes their orifices, so that during fasting
often distinguishable only as minute slightly prominent
When the glands again commence secreting, the epithe-
ates from the deeper part, and together with some of that
e mucous surface of the stomach, is mixed up with the
ed cells containing the gastric fluid.

these tubular or proper gastric glands, certain other
tructures are frequently met with in the stomach. These
paque-white sacculi, like the Peyer's glands of the in-
ed with minute cells and granules, situated chiefly along

the lesser curvature of the stomach beneath the mucous membrane. They are only found during digestion, and it is probable that, having elaborated certain materials of importance to the digestive process, they burst, discharge their contents, and disappear.

Secretion and Properties of the Gastric Fluid.

While the stomach contains no food and is inactive, no gastric fluid is secr[illegible]ed; and [illegible]s either neutral or slightly alkaline, co[illegible]s its [illegible]iediately on the introduction of food or [illegible]to the stomach, the mucous membra[illegible]mes slightly turgid and reddened [illegible]antity of blood, the gastric glands [illegible]and an acid fluid is poured out in m[illegible]s, [illegible]run together and flow down the walls [illegible]he substances introduced.

The na[illegible]ne y[illegible]s secreted, was till lately involved in c[illegible]te obscurity. [illegible]rst accurate analysis of it was made by Dr. Prout; but it does not appear that it was collected in any large quantity, or pure and separate from food, until the time when Dr. Beaumont (cxxxviii.) was enabled by a fortunate circumstance to obtain it from the stomach of a man, named St. Martin, in whom there existed, as the result of a gunshot wound, an opening leading directly into the stomach, near the upper extremity of the great curvature, and three inches from the cardiac orifice. The external opening was situated two inches below the left mamma, in a line drawn from that part to the spine of the left ilium. The borders of the opening into the stomach, which was of considerable size, had united in healing with the margins of the external wound, but the cavity of the stomach was at last separated from the exterior by a fold of mucous membrane, which projected from the upper and back part of the opening, and closed it like a valve, but could be pushed back with the finger. The introduction of any mechanical irritant, such as the bulb of a thermometer, into the stomach, excited at once the secretion of gastric fluid. This could be drawn off with a caoutchouc tube, and could often be obtained to the extent of nearly an ounce. **The introduction of alimentary substances caused a much more rapid and abundant secretion of pure gastric fluid than the presence of other mechanical irritants did. No increase of temperature could be detected during the most active secretion; the thermometer introduced into the stomach always stood at 100° Fahr., except during muscular exertion, when the temperature of the stomach, like that of other parts of the body, rose one or two degrees higher.**

M. Blondlot (xvi.), and subsequently M. Bernard (xix. June, 1844), and since then several others, by maintaining fistulous openings into the stomach of dogs, have confirmed most of the facts dis-

covered by Dr. Beaumont. From their observations, also, it appears that pepper, salt, and other soluble stimulants excite a more rapid discharge of gastric fluid than mechanical irritation does; so do alkalies generally, but acids have a contrary effect. When mechanical irritation is carried beyond certain limits, so as to produce pain, the secretion, instead of being more abundant, diminishes or ceases entirely, and a ropy mucus is poured out instead. Very cold water or small pieces of ice, at first render the mucous membrane pallid, but soon a kind of reaction ensues, the membrane becomes turgid with blood, and a larger quantity of gastric fluid is poured out. The application of too much ice is attended by diminution in the quantity of fluid secreted, and by consequent retardation of the process of digestion. The quantity of the secretion seems to be influenced also by impressions made on the mouth; for M. Blondlot found that when sugar was introduced into the dog's stomach, either alone or mixed with human saliva, a very small secretion ensued; but when the dog had himself masticated and swallowed it, the secretion was abundant.

Dr. Beaumont described the secretion of the human stomach as "a clear transparent fluid, inodorous, a little saltish, and very perceptibly acid. Its taste is similar to that of thin mucilaginous water slightly acidulated with muriatic acid. It is readily diffusible in water, wine, or spirits; slightly effervesces with alkalies; and is an effectual solvent of the *materia alimentaria*. It possesses the property of coagulating albumen in an eminent degree; is powerfully antiseptic, checking the putrefaction of meat; and effectually restorative of healthy action when applied to old fetid sores and foul ulcerating surfaces," (p. 76.)

Dr. Dunglison found in this gastric fluid free hydrochloric and acetic acids, phosphates and hydrochlorates of potash, soda, lime, and magnesia, and an animal matter which was soluble in cold, but insoluble in hot water. The quantity of free hydrochloric acid which he obtained by distillation seems to have been large; and Dr. Prout, as well as other chemists, have satisfied themselves of the existence of this acid in the gastric fluid of the rabbit, hare, horse, calf, and dog. Acetic acid also is said to have been found in the gastric secretion of horses and dogs, as well as by Dr. Beaumont in that of the human subject. But the results of the recent experiments by M. Blondlot (xvi.), Dr. R. D. Thompson (xvii. May, 1845), MM. Bernard and Barreswil (xviii. Dec. 1844), and Lehmann (lix. 1847, p. 102), cast doubt on the opinion that *free* hydrochloric, acetic, or any other volatile acid, exists in this fluid; at least in the case of the dog and pig, the animals experimented on. Having obtained large quantities of pure gastric fluid from the stomach of a dog, and carefully distilled portions of it on the sand-bath, Blondlot found not the slightest trace of acidity in the

product of the distillation; but the residue in the retort was intensely acid, and became more so the more it was concentrated by continuing the distillation. The non-existence of both hydrochloric and acetic acids seeming to be thus demonstrated, Blondlot was led to believe that the acidity of the gastric fluid depends on an acid phosphate of lime. For he observed no effervescence on the addition of carbonate of lime to the acid gastric fluid; neither when carbonate of lime was placed in the gastric fluid was the fluid neutralized or the carbonate dissolved. By further investigation, he demonstrated the existence of a super-phosphate of lime in the gastric fluid. But he seems to have been in error in attributing the whole of the acidity of the gastric fluid to this salt: for MM. Bernard and Barreswil have found that if the gastric fluid be sufficiently concentrated by evaporation, distinct effervescence occurs on the addition of carbonate of lime; proving the presence of some free acid, which they, as well as Dr. R. D. Thompson, Lehmann (lix. 1847, p. 102), and Frerichs (lix. 1850, p. 134), consider to be the lactic, an opinion to which Liebig (liv. p. 138) also gives his sanction. MM. Melsens and Dumas (lix. 1844, p. 109) have also proved the existence of a free acid by the gradual solution of portions of carbonate of lime placed in gastric fluid. But since, even after long contact, the carbonate of lime does not completely neutralize the acid of the gastric fluid, it is most probable that there is, together with the free acid, some acid phosphate of lime, as maintained by M. Blondlot.

Respecting the nature of the free acid, whose presence is thus proved, the discrepant results suggest a supposition that the source of the acidity of the gastric fluid may vary in different animals, or at different times in the same animal. The existence of hydrochloric acid in the human gastric fluid seems to have been clearly determined by Prout and Dunglison, and more recently by Enderlin (lix. 1843, p. 149) and others (see especially, Hübbenet, cxciv.); its non-existence, and the existence of lactic acid, as clearly in the fluid of pigs and dogs by the other analysis just quoted; possibly all are right. The results of experiments in artificial digestion make it probable that the digestive properties of the gastric fluid require only the existence of a certain degree of acidity, which is equally effective whatever be the acid employed, provided this acid does not decompose the active animal principle of the digestive fluid.

The *animal matter* mentioned in the analysis of the gastric fluid by Dr. Dunglison has been since named *pepsine*, from its power in the process of digestion. It is best procured by digesting portions of the mucous membrane of the stomach in cold water, after they have been macerated for some time in water at a temperature be-

en 80° and 100° F. The warm water dissolves various sub-
ices as well as some of the pepsine, but the cold water takes up
le else than pepsine, which, on evaporating the cold solution, is
ined in a grayish-brown viscid fluid. The addition of alcohol
ws down the pepsine in grayish-white flocculi; and one part of
principle thus prepared, if dissolved in even 60,000 parts of
er, will digest meat and other alimentary substances.

The *digestive power of the gastric fluid* is manifested in its
tening, reducing into pulp, and partially or completely dissolv-
various articles of food placed in it at a temperature of from
° to 100°. This, its peculiar property, requires the presence of
th the pepsine and the acid; neither of them can digest alone,
d, when they are mixed, either the decomposition of the pepsine
the neutralization of the acid at once destroys the digestive pro-
rty of the fluid. For the perfection of the process, also, certain
nditions are required, which are all found in the stomach;
mely, first, a temperature of about 100° F.; secondly, such move-
ents as the food is subjected to by the muscular actions of the
omach, which bring in succession every part of it in contact with
e mucous membrane, whence the fresh gastric fluid is being
creted; thirdly, the constant removal of those portions of food
hich are already digested, so that what remains undigested may
brought more completely into contact with the solvent fluid;
d fourthly, a state of softness and minute division, such as that
which the food is reduced by mastication previous to its introduc-
on into the stomach.

The chief circumstances connected with the mode in which the
stric fluid acts upon food during natural digestion have been
termined by watching its operations on different alimentary sub-
ances, when removed from the stomach and placed in conditions
nearly as possible like those in which it acts therein. The fact
at solid food, immersed in gastric fluid out of the body, and kept
a temperature of about 100°, is gradually converted into a thick
uid similar to chyme, was shown by Spallanzani, Dr. Stevens,
iedemann and Gmelin, and others. They used the gastric fluid
f dogs—obtained by causing the animals to swallow small pieces
f sponge, which were subsequently withdrawn soaked with the
uid—and proved nearly as much as the later experiments with
ne same kind of gastric fluid by Blondlot, Bernard, and others.
ut these need not be particularly referred to, while we have the
ore satisfactory and instructive observations which Dr. Beaumont
ade with the fluid obtained from the stomach of St. Martin.
fter the man had fasted seventeen hours, Dr. Beaumont took one
nce of gastric fluid, put into it a solid piece of boiled recently
lted beef weighing three drachms, and placed the vessel which
ntained them in a water-bath heated to 100°. "In forty minutes

digestion had distinctly commenced over the surface of the meat; in fifty minutes, the fluid had become quite opaque and cloudy, the external texture began to separate and become loose; and in sixty minutes chyme began to form. At 1 P. M." (two hours after the commencement of the experiment) "the cellular texture seemed to be entirely destroyed, leaving the muscular fibres loose and unconnected, floating about in fine small shreds, very tender and soft," (cxxxviii. p. 120.) In six hours, they were nearly all digested—a few fibres only remaining. After the lapse of ten hours, every part of the meat was completely digested. The gastric juice, which was at first transparent, was now about the color of whey, and deposited a fine sediment of the color of meat. A similar piece of beef was, at the time of the commencement of this experiment, suspended in the stomach by means of a thread; at the expiration of the first hour it was changed in about the same degree as the meat digested artificially; but, at the end of the second hour, it was completely digested and gone.

In other experiments, Dr. Beaumont withdrew, through the opening in the stomach, some of the food which had been taken twenty minutes previously, and which was completely mixed with the gastric juice. He continued the digestion, which had already commenced, by means of artificial heat in a water-bath. In a few hours, the food thus treated was completely chymified; and the artificial seemed in this, as in several other experiments, to be exactly similar to, though a little slower than, the natural digestion.

The apparent identity of the process within and out of the stomach thus manifested, while it shows that we may regard digestion as essentially a chemical process, when once the gastric fluid is formed, justifies the belief that Dr. Beaumont's other experiments with the digestive fluid may exactly represent the modifications to which, under similar conditions, its action in the stomach would be liable. He found that, if the mixture of food and gastric fluid were exposed to a temperature of 34° F., the process of digestion was completely arrested. In another experiment, a piece of meat which had been macerated in water at the temperature of 100° for several days, till it acquired a strong putrid odor, lost, on the addition of some fresh gastric juice, all signs of putrefaction, and soon began to be digested. From other experiments, he obtained the data for estimates of the degrees of digestibility of various articles of food, and the modes in which the digestion is liable to be affected, to which reference will again be made.

When natural gastric juice cannot be obtained, many of these experiments may be performed with an *artificial digestive fluid*, the action of which, probably, very closely resembles that of the fluid secreted by the stomach. It is made by macerating in water

portions of fresh or dried mucous membrane of the stomach of a pig[1] or other omnivorous animal, or of the fourth stomach of the calf, and adding to the infusion a few drops of hydrochloric acid—about 3.3 grains to half an ounce of the mixture, according to Schwann. Portions of food placed in such fluid, and maintained with it at a temperature of about 100°, are, in an hour or more, according to the toughness of the substance, softened and changed in just the same manner as they would be in the stomach.

The nature of the action by which the mucous membrane of the stomach, and its secretion, work these changes in organic matter, is exceedingly obscure. The action of the pepsine may be compared with that of a ferment, which at the same time that it undergoes change itself, induces certain changes also in the organic matters with which it is in contact. Or its mode of action may belong to that class of chemical processes termed "catalytic," in which a substance excites, by its mere presence, and without itself undergoing change as ordinary ferments do, some chemical action in the substances with which it is in contact. So, for example, spongy platinum placed in a mixture, however voluminous, of oxygen and hydrogen, makes them combine to form water; and diastase makes the starch in grains undergo transformation, and sugar is produced. And that pepsine acts in some such manner appears probable from the very minute quantity capable of exerting the peculiar digestive action on a large quantity of food, and apparently with little diminution in its active power. The process differs from ordinary fermentation in being unattended with the formation of carbonic acid, in not requiring the presence of oxygen, and in being unaccompanied by the production of new quantities of the active principle, or ferment. It agrees with the processes of both fermentation and organic catalysis, in that whatever alters the composition of the pepsine (such as heat above 100°, strong alcohol, or strong acids) destroys the digestive power of the fluid.

Changes of the Food in the Stomach.

The general effect of digestion in the stomach is the conversion of the food into *chyme*, a substance of various composition according to the nature of the food, yet always presenting a characteristic thick, pultaceous, grumous consistence, with the undigested portions of the food mixed in a more fluid substance, and a strong disagreeable acid odor and taste. Its color depends on the nature of the food, or on mixtures of yellow or green bile which may, apparently even in health, pass into the stomach.

[1] The best portion of the stomach of the pig for this purpose is that between the cardiac and pyloric orifices; the cardiac portion appears to furnish the least active digestive fluid.

Reduced into such a substance, all the various materials of a meal may be mingled together, and near the end of the digestive process hardly admit of recognition; but the experiments of artificial digestion, and the examination of stomachs with fistulæ, have illustrated many of the changes through which the chief alimentary principles pass, and the times and modes in which they are severally disposed of. These must now be traced.

The readiness with which the gastric fluid acts on the several articles of food is, in some measure, determined by the state of division, and the tenderness and moisture of the substance presented to it. By minute division of the food, the extent of surface with which the digestive fluid can come in contact is increased, and its action proportionately accelerated. Tender and moist substances offer less resistance to the action of the gastric juice than tough, hard, and dry ones do, because they may be thoroughly penetrated with it, and thus be attacked by it, not only at the surface, but at every part at once. The readiness with which a substance is acted upon by the gastric fluid does not, however, necessarily imply the degree of its nutritive property; for a substance may be nutritious, yet, on account of its toughness or other qualities, hard to digest; and many soft, easily digested substances contain comparatively a small amount of nutriment. But for a substance to be nutritive it must be capable of being assimilated to the blood; and to find its way into the blood, it must, if insoluble, be digestible by the gastric fluid or some other secretion in the intestinal canal. There is, therefore, thus far, a necessary connection between the digestibility of a substance and its power of affording nutriment.

Those portions of food which are liquid when taken into the stomach, or which are easily soluble in the fluids therein, are probably at once absorbed by the bloodvessels in the mucous membrane of the stomach. Magendie's experiments, and, better still, those of Dr. Beaumont, have proved this quick absorption of water, wine, weak saline solutions, and the like; that they are absorbed without manifest change by the digestive fluid; and that, generally, the water of such liquid food as soups is absorbed at once, so that the substances suspended in it are concentrated into a thicker material, like the chyme from solid food, before the digestive fluid acts upon them.

The *action of the gastric fluid* on the several kinds of *solid food* has been studied in various ways. In the earliest experiments, perforated metallic and glass tubes, filled with the alimentary substances, were introduced into the stomachs of animals, and after the lapse of a certain time withdrawn, to observe the condition of the contained substances; but such experiments are fallacious, because gastric fluid has not ready access to the food. A better method was practised in a series of experiments by Tiedemann

d Gmelin, who fed dogs with different substances, and killed em in a certain number of hours afterwards. But the results ey obtained are of less interest than those of the experiments of r. Beaumont, on his patient, St. Martin, and of Dr. Gosse xxxvii.), who had the power of vomiting at will.

Dr. Beaumont's observations show that the process of digesn in the stomach, during health, takes place so rapidly that a ll meal, consisting of animal and vegetable substances, may nearly l be converted into chyme in about an hour, and the stomach left npty in two hours and a half. The detail of two days' experiments ill be sufficient examples:—

Exp. 42. April 7, 8 A. M.—St. Martin breakfasted on three hard-oiled eggs, pancakes, and coffee. At half-past eight o'clock, Dr. eaumont examined the stomach, and found a heterogeneous mixre of the several articles slightly digested....At a quarter past n, no part of the breakfast remained in the stomach.

Exp. 43.—At eleven o'clock the same day, he ate two roasted ggs and three ripe apples. In half an hour they were in an inipient state of digestion; and at a quarter past twelve no vestige f them remained.

Exp. 44.—At two o'clock P. M. same day he dined on roasted ig and vegetables. At three o'clock they were half chymified, nd at half-past four nothing remained but a very little gastric uice.

Again, Exp. 46. April 9.—At three o'clock P. M. he dined on oiled dried codfish, potatoes, parsneps, bread, and drawn butter. t half-past three o'clock examined, and took out a portion about alf digested; the potatoes the least so. The fish was broken own into small filaments; the bread and parsneps were not to be istinguished. At four o'clock examined another portion. Very ew particles of fish remained entire. Some of the few potatoes ere distinctly to be seen. At half-past four o'clock took out nd examined another portion; all completely chymified. At five 'clock stomach empty (p. 158).

Many circumstances besides the nature of the food are apt to nfluence the process of chymification. Among them are, the uantity of food taken; the stomach should be fairly filled, not i-tended: the time that has elapsed since the last meal, which hould be at least enough for the stomach to be quite clear of food; he amount of exercise previous and subsequent to the meal, gentle xercise being favorable, over-exertion injurious to digestion; the tate of mind, tranquillity of temper being apparently essential to quick and due digestion: the bodily health: the state of the eather. But under ordinary circumstances, from three to four ours may be taken as the average time occupied by the complete igestion of a meal.

Dr. R[illegible]nt constructed a table showing the time required for the d[illegible]f all usual articles of food in St. Martin's stomach, and i[illegible]tric fluid taken from the stomach. Among the substances [illegible]quickly digested were rice and tripe, both of which were chyme[illegible] in an hour; eggs, salmon, trout, apples, and venison, were digested in an hour and a half; tapioca, barley, milk, liver, fish, in two hours; [illegible]toes, pig, in two hours and a half; beef and mu[illegible] three hours to three and a half, and both wer[illegible] than veal; fowls were like mutton in their [illegible]y. Animal substances were, in general, conv[illegible]e rapidly than vegetables.

Dr. Beaum[illegible]all made on ordinary articles of food. A[illegible]of the changes produced by gastric diges[illegible] has been lately made by Dr. Rawitz (xxvi.), who [illegible]copically the products of the artificial digestion of u[illegible]f food, and the contents of the feces after eating the same kinds of food. The general results of his examinations, as regards *animal* food, show that muscular tissue breaks up into its constituent fasciculi, and that these again are divided transversely; gradually, the transverse striæ become indistinct, and then disappear; and finally, the sarcolemma seems to be dissolved, and no trace of the tissue can be found in the chyme, except a few fragments of fibres. These changes ensue most rapidly in the flesh of fish and hares, less rapidly in that of poultry and other animals. The fragments of muscular tissue which remain after the continued action of the digestive fluid, do not appear to undergo any alteration in their passage through the rest of the intestinal canal, for similar fragments may be found in feces even twenty-four hours after the introduction of the meat into the stomach. The cells of cartilage and fibro-cartilage, except those of fish, pass unchanged through the stomach and intestines, and may be found in the feces. The interstitial tissues of these structures are converted into pulpy textureless substances in the artificial digestive fluid, and are not discoverable in the feces. Elastic fibres are unchanged in the digestive fluid. Fatty matters also are unchanged; fat-cells are sometimes found quite unaltered in the feces: and crystals of cholestearine may usually be obtained from feces, especially after the use of pork-fat.

As regards *vegetable* substances, Dr. Rawitz states that he frequently found large quantities of cell-membranes unchanged in the feces; also starch-cells, commonly deprived of only part of their contents. The green coloring principle, chlorophyll, was usually unchanged. The walls of the sap-vessels and spiral-vessels were quite unaltered by the digestive fluid, and were usually found in large quantities in the feces; their contents, probably, were removed.

From these experiments we may understand the *structural* changes which the chief alimentary substances undergo in their conversion into chyme; and the proportions of each which are not reducible to chyme, nor capable of any further act of digestion. The *chemical* changes undergone in and by the proximate principles are less easily traced.

Of the *albuminous* principles, the caseine of milk, and, according to Dr. Beaumont, fluid albumen, are coagulated by the acid of the gastric fluid; and thus, before they are digested, come into the condition of the other solid principles of the food. These, including solid albumen and fibrine, in the same proportion as they are broken up and anatomically disorganized by the gastric fluid, appeared to be reduced or *lowered* in their chemical composition (see Prout, xxi. p. 366, Am. Ed.). This chemical change is probably produced, as suggested by Dr. Prout, by the principles entering into combination with water. It is sufficient to conceal nearly all their characteristic properties; the albumen is made scarcely coagulable by heat; the gelatine, even when its solution is evaporated, does not congeal in cooling; the fibrine and caseine cannot be found by their characteristic tests. It would seem, indeed, as if all these various substances were converted into one and the same principle, a low form of albumen, from which, after being absorbed, they are again raised in the elaboration of the chyle and blood to which they are assimilated.

Whatever be the mode in which the gastric secretion affects these principles, it, or something like it, appears essential in order that they may be assimilated to the blood and tissues For, when Bernard and Barreswil injected albumen dissolved in water into the jugular veins of dogs, they always, in three hours after, found it in the urine. But if, previous to injection, it was mixed with gastric fluid, no trace of it could be detected in the urine. Similar results also ensue, if the albumen, unmixed with gastric fluid, passes through the liver before it enters the general circulation. For Bernard has recently found that when injected into the portal vein, albumen is at once assimilated, and is consequently not found in the urine (xix. 1850).

The *saccharine* including the *amylaceous* principles are at first, probably, only mechanically separated from the vegetable substances within which they are contained, by the action of the gastric fluid. The soluble portions, viz., sugar, gum, and pectine, are probably at once absorbed. The insoluble ones, viz., starch and lignine (or some parts of it), are rendered soluble and capable of absorption, by being converted into dextrine and grape-sugar. It is probable that this change is carried on to some extent in the stomach, though not by the action of the gastric fluid, but of the salivary secretion with which it has become mixed; for many experiments, including

those of Dr. Percy (lxxi. April, 1843), show that starch is absorbed from the stomach, being, of course, previously rendered soluble. But the change is continued in the intestinal canal, probably, as will be shown, under the influence of the secretion of the pancreas, and of that of the intestinal glands and mucous membrane. And, further, respecting the action of the stomach in the digestion of starch, it may be doubted whether the human stomach has any power over it in the raw state; for both by man and Carnivora, when starch has been taken raw, as in corn and rice, large quantities of the granules are passed unaltered with the excrements. Cooking, by expanding or bursting the envelops of the granules, renders their interior more amenable to the action of the digestive organs; and the abundant nutriment furnished by bread, and the large proportion that is absorbed of the weight of it consumed, afford proof of the completeness of their power to makes its starch soluble and prepare it for absorption.

Of the *oleaginous principles*, as to their changes in the stomach, no more can be said than that they appear to be reduced to minute particles, and pass into the intestines mingled with the other constituents of the chyme. Being further changed in the intestinal canal, they are rendered capable of absorption by the lacteals.

Movements of the Stomach.

It has been already said that the gastric fluid is assisted towards accomplishing its share in digestion by the movements of the stomach. In granivorous birds, for example, the contraction of the strong muscular gizzard affords a necessary aid to digestion by grinding and triturating the hard seeds which constitute part of the food. But in the stomachs of man and Mammalia, the motions of the muscular coat are too feeble to exercise any such mechanical force on the food; neither are they needed; for mastication has already done the mechanical work of a gizzard; and the experiments of Reaumur and Spallanzani have demonstrated that substances inclosed in perforated tubes, and consequently protected from mechanical influence, are yet digested.

The normal actions of the muscular fibres of the human stomach appear to have a threefold purpose; first, to adapt the stomach to the quantity of food in it, so that its walls may be in contact with the food on all sides, and at the same time may exercise a certain amount of compression upon it; secondly, to keep the orifices of the stomach closed until the food is digested, and then, permitting the pyloric orifice to open, to expel the chyme through it into the intestines; and, thirdly, to produce certain movements among the contents of the stomach whereby the thorough intermingling of the food and gastric fluid may be facilitated.

When digestion is not going on, the stomach is uniformly con-

its orifices not more firmly than the rest of its walls; but, ined shortly after the introduction of food, it is found closely ng its contents, and its orifices are firmly closed like sphinc- The cardiac orifice, every time food is swallowed, opens to ts passage into the stomach, and immediately again closes. loric orifice, during the first part of gastric digestion, is so completely closed, that even when the stomach is sepa- rom the intestines, none of its contents escape. But towards mination of the digestive process, the pylorus seems to offer istance to the passage of substances from the stomach; first ls to allow the successively digested portions to go through d then it allows the transit of even undigested substances.

m the observations of Dr. Beaumont on the man St. Martin, ars that food, as soon as it enters the stomach, is subjected action of the muscular coat, whereby it is moved through the s and along the great curvature from left to right, and then the lesser curvature from right to left. He perceived the of the same motions in the changes of position which the f a thermometer, whose bulb was introduced into the stomach, ent. Each of these circular motions occupied from one to minutes. They increased in rapidity as the process of chymi- n advanced, and continued until it was completed.

e contraction of the fibres situated towards the pyloric end of omach, seems to be more energetic and more decidedly peri- than those of the cardiac portion. Thus, Dr. Beaumont that when the bulb of the thermometer was placed about inches from the pylorus, it was tightly embraced from time e and drawn towards the pyloric orifice for a distance of three r inches. The object of this movement appears to be to carry od towards the pylorus as fast as it is formed into chyme, and pel the chyme into the duodenum; the undigested portions d being kept back until they also are reduced into chyme, or all that is digestible has passed out. The action of these is often seen in the contracted state of the pyloric portion of omach after death, when it alone is contracted and firm, while ardiac portion forms a dilated sac. Sometimes, by a predomi- action of strong circular fibres placed between the cardia pylorus, the two portions, or ends, as they are called, of the ch, are separated from each other by a kind of hour-glass con- on.

ese actions of the stomach are peculiar to it, and independent. t is also adapted to act in concert with the abdominal muscles, rtain circumstances which can hardly be called anormal, as in ing and eructation. It has, indeed, been frequently stated he stomach itself is quite passive during vomiting, and that xpulsion of its contents is effected solely by the pressure ex-

erted upon it when the capacity of the abdomen is diminished by the contraction of the diaphragm and abdominal muscles: and this opinion has been especially supported by M. Magendie (xxxii. p. 356, Am. Ed.). After having injected tartar emetic into the veins of dogs, and in other instances given it by the mouth, he states that he never saw the stomach itself contract; and that, if in such cases he drew the stomach out of the abdominal cavity, vomiting was prevented until he returned it to its natural situation, when vomiting immediately ensued. Pressure with the hand had the same influence as the contraction of the muscles; and even the action of the diaphragm alone, or the linea alba, was sufficient to produce vomiting when the abdominal muscles had been cut away. When the stomach was pierced, and a pig's bladder connected with the wound, vomiting was produced in the same way, and the stomach itself remained uninjured. The latter observation, however, only proves that the pressure exerted by the contracting abdominal muscles upon an unresisting bag, is sufficient to expel its contents. And the others do not show more than that a considerable share in the act of vomiting is exercised by the abdominal muscles.

On the other hand, many facts seem to prove that the stomach takes an active part in the expulsion of its own contents. In a case, for example, which fell under the notice of M. Lepine (Iv. 1844), the abdomen of the patient was torn open by a horn, and the stomach was wholly protruded. For half an hour it was seen repeatedly and forcibly contracting itself, till by its own efforts it expelled all its contents except the gases. Moreover, during vomiting, the contraction of the stomach can usually be distinctly felt by the patient; though, at least in animals, it appears to be often so slight and rapid, that even when the stomach is exposed, its occurrence might be overlooked.

Besides taking this share by its contraction, the stomach also essentially contributes to the act of vomiting, by the relaxation of the oblique fibres around the cardiac orifice, coincidently with the contraction of the abdominal muscles and of the rest of its own fibres. For, until the relaxation of these fibres, no vomiting can ensue; when contracted, they can as well resist all the force of the contracting abdominal and other muscles, as the muscles by which the glottis is closed can resist the same force in the act of straining. Doubtless we may refer many of the acts of retching and ineffectual attempts to vomit to the want of concord between the relaxation of these muscles and the contraction of the rest.

The muscles with which the stomach co-operates in contraction during vomiting, are chiefly and primarily those of the abdomen; the diaphragm also acts, but not as the muscles of the abdominal walls do. They contract and compress the stomach more and more

towards the back and upper parts of the diaphragm; and the diaphragm (which is usually drawn down in the deep inspiration that precedes each act of vomiting) holds itself fixed in contraction, and presents an unyielding surface against which the stomach may be pressed. It is enabled to act thus, and probably only thus, because the inspiration which precedes the act of vomiting is terminated by closure of the glottis; after which the diaphragm can neither descend further, except by expanding the air in the lungs; nor, except by compressing the air, ascend again until, the act of vomiting having ceased, the glottis is opened again.

Some persons possess the power of vomiting at will, without applying any undue irritation to the stomach, but simply by a voluntary effort. It seems also that this power may be acquired by those who do not naturally possess it, and by continual practice may become a habit. Cases are also of no rare occurrence in which persons habitually swallow their food hastily, and nearly unmasticated; and then, at their leisure, regurgitate it piece by piece into their mouth, remasticate, and again swallow it, exactly as is done by the ruminant order of Mammalia.[1]

Influence of the Nervous System on Gastric Digestion.

This influence is manifold; and is evidenced, 1st, in the sensations which induce to the taking of food; 2d, in the secretion of the gastric fluid; 3d, in the movements of the food in and from the stomach.

The *sensation of hunger* is manifested in consequence of deficiency of food in the system. The mind refers the sensation to the stomach; yet, since the sensation is relieved by the introduction of food either into the stomach itself, or into the blood through other channels than the stomach, it would appear not to depend on the state of the stomach alone. This view is confirmed by the fact that the division of both pneumogastric nerves, which are the principal channels by which the mind is cognizant of the condition of the stomach, does not appear to allay the sensations of hunger. (Reid, lxxiii. vol. iii. p. 899.)

But that the stomach has some share in this sensation, is proved by the relief afforded, though only temporarily, by the introduction of even non-alimentary substances into this organ. It may, therefore, be said that the sensation of hunger is derived from the system generally, but chiefly from the condition of the stomach; the nerves of which, we may suppose, are more affected by the state of the insufficiently replenished blood than those of other organs are.

The sensation of thirst, indicating the want of fluid, is referred

[1] For a recent essay on the movements of the stomach, see Dr. Brinton (lxxi. 1849).

to the fauces, although, as in hunger, this is merely the local declaration of a general condition existing in the system. For thirst is relieved for only a very short time by washing the dry fauces; but may be relieved completely by the introduction of liquids into the blood, either through the stomach, or by injections into the bloodvessels, or by absorption from the surface of the skin, or the intestines. The sensation of thirst is perceived most naturally whenever there is a disproportionately small quantity of water in the blood; as well, therefore, when water has been abstracted from the blood, as when saline, or any solid matters have been abundantly added to it. We can express the fact (even if it be not an explanation of it), by saying that the nerves of the mouth and fauces, through which the sense of thirst is chiefly derived, are more sensitive to this condition of the blood than other nerves are. And the cases of hunger and thirst are not the only ones in which the mind derives, from certain organs, a peculiar predominant sensation of some condition affecting the whole body. Thus, the sensation of the "necessity of breathing," is referred especially to the lungs; but, as Volkmann's experiments show, it depends on the condition of the blood which circulates everywhere, and is felt even after the lungs of animals are removed; for they continue, even then, to gasp and manifest the sensation of want of breath. So, perhaps, it may be added, the disordered blood of fever, and other affections of the blood, circulates everywhere, but produces peculiar sensations in only certain parts. And, as with respiration, when the lungs are removed, the mind may still feel the body's want of breath, so in hunger and thirst, even when the stomach has been filled with innutritious substances, or the pneumogastric nerves have been divided, and the mouth and fauces are kept moist, the mind is still aware, by the more obscure sensations in other parts, of the whole body's need of food and water.

The *influence of the nervous system on the secretion of gastric fluid*, is shown plainly enough in the influence of the mind upon digestion in the stomach; and is, in this regard, well illustrated by several of Dr. Beaumont's observations. M. Bernard, also, watching the act of gastric digestion in dogs, who had fistulous openings into their stomachs, saw that, on the instant of dividing their pneumogastric nerves, the process of digestion was stopped, and the mucous membrane of the stomach, previously turgid with blood, became pale and ceased to secrete. These, however, and the like experiments, showing the instant effects of division of the pneumogastric nerves, may prove no more than the effect of a severe shock, and that influences affecting digestion may be conveyed to the stomach through those nerves. From other experiments it may be gathered that, although, as in M. Bernard's, the division of both pneumogastric nerves always temporarily suspends the secretion of gastric fluid,

rests the process of digestion, and is occasionally followed from inanition, yet the digestive powers of the stomach ompletely restored after the operation, and the formation and the nutrition of the animal may be carried on almost ly as in health. (Reid, lxxiii. vol. iii. p. 900, and Hübbenet,

been said that after the division of the pneumogastric he absorption of poisons by the stomach does not take is more slowly effected. But in thirty experiments on in, which M. Wernscheidt performed under Müller's , not the least difference could be perceived in the action tic poisons introduced into the stomach, whether the astric had been divided on both sides or not, provided the were of the same species and size. It appears, however, h poisons as are capable of being rendered inert by the the gastric fluid, may, if taken into the stomach shortly ision of both pneumogastric nerves, produce their poisonous n consequence, apparently, of the temporary suspension of tion of gastric fluid. Thus, in one of his experiments, M. gave to each of two dogs, in one of which he had divided umogastric nerves, a dose of emulsine, and half an hour ds a dose of amygdaline, substances which are innocent at when mixed produce hydrocyanic acid. The dog whose rere cut, died in a quarter of an hour, the substances being l unaltered and mixing in the blood; in the other, the was decomposed by the gastric fluid before the amyg- was administered; therefore, hydrocyanic acid was not n the blood, and the dog survived. The results of these nts have been recently confirmed by Frerichs (xv. art. *ung*).

influence of the nervous system on the movements of the has been often seen in the retardation or arrest of these nts after division of the pneumogastric nerves. The results ing the same nerves were ambiguous; but the experiments et (cxxxvi. vol. i. p. 323) and Bischoff (lxxx. 1843, *richt*, p. clv.) have shown that the different results depended ther the stomach were digesting or not at the time of the nt. In the act of digestion, the nervous system of the appears to participate in the excitement which prevails the rest of its organization, and a stimulus applied to the astric nerves is felt intensely, and active movements of the fibres of the stomach follow; but in the inaction of fasting stimulus produces no effect. So, while the stomach is , the pylorus is too irritable to allow anything but chyme but when digestion is ended, the undigested parts of the even large bodies, coins and the like, may pass through it.

Experiments have done little to explain the influence of the sympathetic nerves and their ganglia, on the movements and secretions of the stomach.

CHANGES OF THE FOOD IN THE INTESTINES.

In the intestines, the passage of the chyme into which has been just described, the l.. on and digested, is exposed to the influence of t itic fluid, and the secretions of the several gl and forming the intestinal mucous membrane. hese various secretions, the chyme undergoes fu ter which, being more perfectly separated from parts of the food, it is absorbed by the bloody ; and the rest of the food, with portions of the tions, is ejected in feces.

Structure and Secretions of the Intestines.

The intestinal canal is divided into two chief portions, named, from their differences in diameter, the *small* and the *large* intestines, which are separated from each other by a muscular valvular structure, the ileo-cæcal valve. This distinction is much less marked in Carnivora, than in Herbivora; the large intestine in the latter class of animals being very wide and long. The small intestine, for convenience of description, has been further divided into three portions, viz: the *duodenum*, which extends for eight or ten inches beyond the pylorus; the *jejunum*, which occupies two-fifths, and the *ileum*, which occupies three-fifths, of the rest of this portion of the canal. The large intestine also is subdivided into three portions, viz., the *cæcum*, a short, wide pouch, separated from the small intestines by the *ileo-cæcal* valve; the *colon*, which occupies the principal part of the large intestine, and is divided into an ascending, transverse, and descending portion; and the rectum, which terminates at the anus. The cæcum is said to be absent in all animals which hybernate: it is small in Carnivora, and very large and long in the Solidungula, Ruminantia, and Rodentia, in which there is reason to believe that it has an especially active part in the digestion of the food which has not been perfectly transformed in the stomach.

The intestines, like the stomach, are constructed of three principal coats, viz., the serous, muscular, and mucous. The fibres of the muscular coat of the small intestine are arranged in two layers; those of the outer layer being disposed longitudinally; those of the inner layer transversely, or, in portions of circles encompassing the canal. In the cæcum and colon, besides those longitudinal fibres which, as in the small intestines, are thinly disposed on all parts of the walls, others are collected into three strong bands,

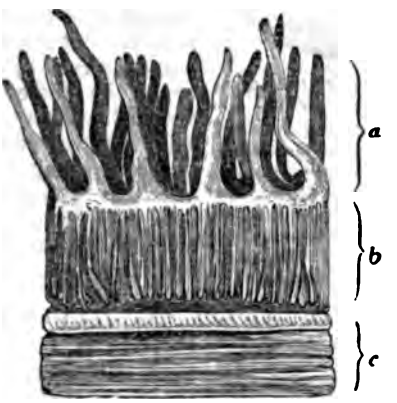
are so connected with the other coats of the intestine, espe- with the peritoneal coats, that they hold the canal in folds ing intermediate sacculi. At the rectum, the fasciculi of these idinal bands, or *ligaments* of the colon, as they are called, out, and mingle with the other longitudinal fibres, forming hem a thicker layer of longitudinal fibres than exists on her part of the intestinal canal.

mucous membrane of the small intestine has its surface y extended by being formed in transverse folds, termed *e conniventes.* These commence in the duodenum, are largely ped therein directly beyond the orifice of the bile-duct, and, ing the same large size, and closely placed, are continued gh the whole of the jejunum, and then, gradually diminishing and closeness of juxtaposition, they cease near the middle ileum. No similar folds exist in any part of the large in- s.

the substance of the mucous membrane of the small intestine rous *glands* are imbedded; its surface is studded with minute ses termed *villi;* and it is covered throughout with cylindrical *lium.*

glands of the small intestine are of three principal kinds,

Fig. 35.



a of the mucous membrane of the small intestine in the dog, showing Lieber- follicles and villi.

B. *b.* Lieberkühn's follicles. *c.* Other coats of the intestine.

l after their describers, the glands of Lieberkühn (lxxv.), of (lxxvi.), and of Brunn or Brunner. (lxxvii.) The *glands licles of Lieberkühn* are simple tubular depressions of the in-

testinal mucous membrane, thickly distributed over the whole surface both of the large and small intestines.[1] (Fig. 35.) In the small intestine, these are visible only with the aid of a lens, and their orifices appear as minute dots scattered between the villi. They are larger in the large intestine, and increase in size the nearer they approach the anal end of the intestinal tube, and in the rectum their orifices may be visible to the naked eye. Each tubule or follicle is cor same essential parts as the intestinal mucous mem ne structureless *membrana propria*, or basement-m er of cylindrical epithelium lining it, and capillary ering its exterior. (Fig. 36.) contents appear to vary, even lth; the varieties being de nt, probably, on the period e in relation to digestion at they are examined. At the bottom of the follicle the contents usually consist of a granular material, in which a few cytoblasts or nuclei are imbedded: these cytoblasts, as they ascend towards the surface, are supposed to be gradually developed into nucleated cells, some of which are discharged into the intestinal cavity. The purpose served by the material secreted by these glands is still doubtful. Their large number, and the extent of surface occupied by them, seem, however, to indicate that they are concerned in other and higher offices than the mere production of fluid to moisten the surface of the mucous membrane.

Fig. 36.

A. Transverse section of Lieberkühn's tubes or follicles, showing the basement-membrane and subcolumnar epithelium of their walls, with the areolar tissue which connects the tubes. *a*. Basement-membrane and epithelium, constituting the wall of the tube. *b*. Cavity or lumen of the tube. Magnified 200 diameters.

B. A single Lieberkühn's tube, highly magnified. A happy accidental section in the oblique direction has served to display very distinctly the form and mode of packing of the epithelial particles, the cavity of the tube, and the mosaic pavement of its exterior. *a*. Basement-membrane. *c* Internal surface ofthe wall of the tube. Magnified 200 diameters.

The *glands of Peyer* occur exclusively in the small intestine. They are found in the greater abundance the nearer to the ileo-cæcal valve. They are met with in two conditions, viz., either scattered singly, in which case they are termed *glandulæ solitariæ*, or aggregated in groups of various sizes, chiefly of an oval form, and

[1] Lieberkühn only described them as existing in the small intestine; Boehm (lxxvii.) first pointed out their existence over the whole extent of the large intestine also.

situated opposite the attachment of the mesentery. In this state they are named *glandulæ agminatæ*, the groups being commonly called *Peyer's patches*. In structure, and probably in function, there is no essential difference between the solitary glands and the individual bodies of which each group or patch is made up; but the surface of the solitary glands (Fig. 37) is beset with villi, from which those forming the agminate patches (Fig. 38) are usually free.

Fig. 37. Fig. 38.

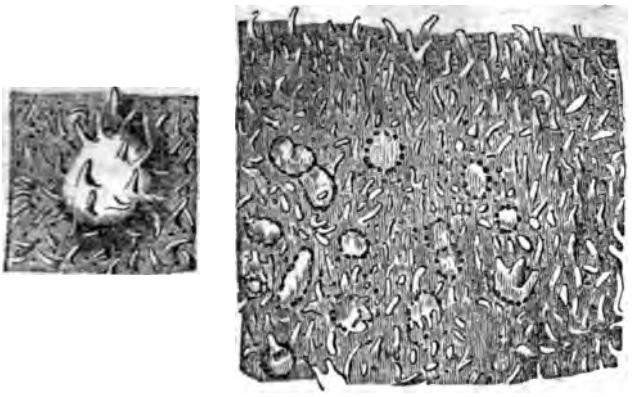


Fig. 37. Solitary gland of small intestine. After Boehm.

Fig. 38. Part of a patch of the so-called Peyer's glands magnified, showing the various forms of the sacculi, with their zone of foramina. The rest of the membrane marked with Lieberkühn's follicles and sprinkled with villi. After Boehm.

In the condition in which they have been most commonly examined, each gland appears as a circular, opaque, white sacculus, from half a line to a line in diameter, and, according to the degree in which it is developed, either sunk beneath, or more or less prominently raised on, the surface of a depression or fossa in the mucous membrane. Each gland is surrounded by openings like those of Lieberkuhn's follicles (see Figs. 38, 39), except that they are more elongated; and the direction of the long diameter of each opening is such that the whole produce a radiated appearance around the white sacculus. These openings appear to belong to tubules like Lieberkuhn's follicles; they have no communication with the sacculus, and none of its contents escape through them on pressure. Neither can any permanent opening be detected in the sacculus or Peyer's gland itself. (See Fig. 39.)

According to Henle's view, which is now generally adopted, each of these glands may be regarded as a secreting cell, which, when

Fig. 39.

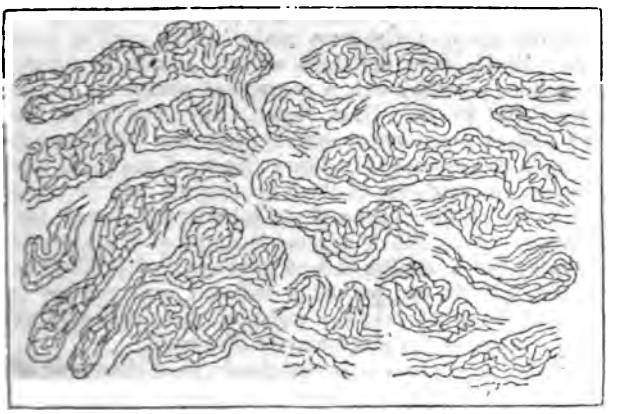
Side view of a portion of intestinal mucous membrane of a cat, showing a Peyer's gland (*a*): it is imbedded in the submucous tissue (*f*), the line of separation between which and the mucous membrane passes across the gland: *b*, one of the tubular follicles, the orifices of which form the zone of openings around the gland: *c*, the fossa in the mucous membrane: *d*, villi: *e*, follicles of Lieberkühn. After Bends (lxxix).

its contents are fully matured, forms a communication with the cavity of the intestine by the absorption or bursting of its own cell-wall and of the portion of mucous membrane over it; thus it discharges its secretion into the intestinal tube. A small shallow cavity or space remains for a time after this absorption or dehiscence, but shortly disappears, together with all trace of the previous gland. The opaque white contents of the Peyer's glands consist of minute granules and cells, but of their nature and purpose nothing is known; only it is probable they assist in digestion, because the glands are usually most developed when the rest of the mucous membrane presents most signs of activity in digestion and absorption. Ernst Brücke believes them to be absorbent glands destined to elaborate the elements of chyle, and he states, in support of this view, that he has been able to inject the lacteals through these glands (clxxxix. Nov. 1850).

Brunner's glands are confined to the duodenum; they are most abundant and thickly set at the commencement of this portion of the intestine, diminishing gradually as the duodenum advances. They are situated beneath the mucous membrane, imbedded in the submucous tissue, minutely lobulated bodies, visible to the naked eye, like detached small portions of panereas, and provided with permanent gland-ducts, which pass through the mucous membrane and open on the internal surface of the intestine. As in structure so probably in function, they resemble the pancreas; or at least stand to it in a similar relation to that which the small labial and buccal glands occupy in relation to the larger salivary glands, the parotid and sub-maxillary.

The *Villi* are confined exclusively to the mucous membrane of the small intestine. They are minute vascular processes (Fig. 40) from a quarter of a line to a line and two-thirds in length (Müller, xxxii. p. 271, Am. Ed.), covering, in the proportion of about twenty-five on every square line, the surface of the mucous membrane (Lieberkühn, lxxv.), and giving it a peculiar velvety, fleecy appearance. They

Fig. 40.



Capillary plexus of the villi of the human small intestine, as seen on the surface, after a successful injection, magnified 50 diameters.

Fig. 41.

One of the intestinal villi, with the commencement of a lacteal.

vary in form even in the same animal, and differ according as the vessels they contain are empty or full of chyle; being usually, in the former case, flat and pointed at their summits, in the latter cylindrical or clavate. Into the base of each villus there enter one or more lacteal vessels, which are believed to divide and anastomose, and form a network which extends nearly to the extremity of the villus (Krause, lxxx. 1837; Valentin, lxxx. 1839; E. H. Weber, lxxx. 1847, p. 400). Two or more minute arteries are distributed within each villus, and from their capillaries proceed one or two small veins, which pass out at the base of the villus (see Fig. 23, p. 104). Being a process of the mucous membrane, each villus possesses an investing basement-membrane, the outer surface of which is covered with a layer of cylindrical epithelium, similar to that which invests every other part of the intestinal mucous membrane, and lines the tubular follicles of Lieberkühn.

The office of the villi is the absorption of chyle from the completely digested food in the intestines. The mode in which they effect this will be considered in the chapter on ABSORPTION.

The *glands of the large intestine* are of two kinds, viz., the tubu-

lar follicles of Lieberkühn already described, and certain *solitary* glands which are scattered over the whole length of this part of the intestines, but are most numerous in the cœcum and its vermiform appendix. Boehm described these solitary glands as simple flask-shaped cavities, provided with a permanent orifice at the apex of the cavity. But Dr. Baly (lxxi. March, 1847) has shown that they have not always a permanent opening, but are sometimes closed, resembling in this respect the solitary glands of the small intestine. When closed, the existence of these glands can only be recognized by the absence of the orifices of the tubular follicles at the spots which they occupy. When a gland is emptied of its contents, it often happens that a number of the adjoining tubular follicles appear to be drawn inwards, and present a radiated arrangement around the centre of the gland. In the midst of these radiating tubular follicles the orifice of the gland may be discerned.

Of the functions of these intestinal glands, as of the others already mentioned, nothing is known. The difficulty of determining the function of any single set of the intestinal glands must, indeed, seem almost insuperable: while so many fluids are discharged together into the intestine, and all acting, probably, at once, produce a general effect upon the food, it is almost impossible to discern the share of each. On this ground, the changes that the food undergoes in the intestines must be deferred till all the fluids that act upon it have been described.

The Pancreas, and its Secretion.

The pancreas is situated within the curve formed by the duodenum, and its main duct opens into that intestine, either through a small opening or through a duct common to itself and to the liver. The pancreas, in its minute anatomy, closely resembles the salivary glands; and the fluid elaborated by it appears almost identical with saliva. When obtained pure, in all the different animals in which it has been hitherto examined, it has been found colorless, transparent, and slightly viscid. The most recent investigations tend to confirm the account given by Leuret and Lassaigne, that when fresh it is alkaline and contains an animal matter and certain salts, both of which are similar to those found in saliva, except in that there is no sulpho-cyanogen. Like saliva, the pancreatic fluid, shortly after its escape, becomes neutral and then acid. Most of the earlier, and some of the recent examiners state that it contains a certain quantity of albumen; but it is probable that this was only an accidental ingredient in the specimens examined; for M. Blondlot (xvi. p. 124), who obtained a considerable quantity of pure secretion from the pancreas of a dog, states that he could not find a trace of albumen in it. (See also Frerichs, xv. art. *Verdauung*.)

Numerous experiments have shown that starch is acted upon by

creatic fluid, or by portions of pancreas put in starch-paste, ame manner as it is by saliva and portions of the salivary

And although, as before stated (p. 162), many substances those glands can excite the transformation of starch into e and grape-sugar, yet it appears not improbable that the tic fluid, exercising this power of transformation, is subser- o the purpose of digesting starch. MM. Bouchardat and (xix. Jan. 1845) have shown that the raw starch-granules ave passed unchanged through the crops and gizzards of rous birds, or through the stomachs of herbivorous Mam- re, in the small intestine, disorganized, eroded, and finally d, as they are when exposed, in experiment, to the action pancreatic fluid. The bile cannot effect such a change in ; but it remains yet to be proved whether the pancreas or stinal mucous membrane have the greater share in it, for em to possess the powers of converting the starch into sugar. he Action of the Intestinal Secretion alone on Starch, see net, cxiv.)

eover, the existence of a pancreas in the Carnivora indicates must serve some purpose besides that of digesting starch. ps it may assist in the digestion of fat, or in rendering it fit sorption; for numerous cases are recorded in which the pan- duct being obstructed so that the secretion could not be rged, fatty or oily matter was abundantly discharged from testines (xli. vol. xviii. p. 57). In nearly all these cases, , the liver was coincidently diseased, and the change or ab- of the bile might appear to contribute to the result; but in t one[1] the liver was healthy, and there appeared nothing but sence of the pancreatic fluid from the intestines to which the ion or non-absorption of fatty matter could be ascribed.

reover, Claude Bernard has lately stated, and has brought for- bundant evidence in support of his statement, that the ex- se of the pancreatic fluid is to render the fatty matters capa- absorption by the lacteals, by transforming them into fatty nd glycerine.[2] Evidence of a contrary kind, however, has nore recently advanced by Dr. Lenz (cxcvi.), and Dr. Frerichs rt. *Verdauung*). They tied the pancreatic duct in cats, and keeping them fasting for some time, to allow of the entire al of the pancreatic fluid which might have passed into the ne, they fed them with milk and fat meat, and found on kill- em and opening their intestinal canal, that the lacteals were rith ordinary milky chyle. Moreover, in young dogs, Fre- pplied a ligature around the upper part of the small intestine the entrance of the pancreatic duct, and then injected milk

[1] Museum, St. Bartholomew's Hospital. Series xx. No. 2.
[2] See Amer. Journ. of Med. Sciences, Oct. 1851.

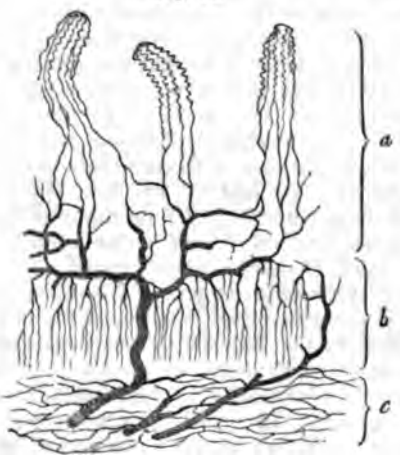
and oil into the lower part of the intestine, and found that the oily matters were completely absorbed by the lacteals. These and other equally weight[illegible] arguments must make us hesitate, at least for the present, to give credence to M. Bernard's statement.

The Liver, and its Secretion.

Structure of the Liver.—The liver receives blood through two vessels, the hepatic [illegible]tal vein. The former, conveying arterial blood, [illegible]stined chiefly for the nutrition of the coats of [illegible] the ducts, and the investing membranes belo[illegible]lying these parts with blood as the bronchial [illegible]ponding parts in the lungs (see p. 132). [illegible]ch carries venous blood, are supplied the mat[illegible]n of bile.

The tributary [illegible]nvergence and junction of which the main [illegible]ein is formed, comprise the veins which receive the b[illegible] stomach and intestinal canal, the spleen, pancreas, and gall-bladder (Fig. 42.). The trunk thus

Fig. 42.



Vertical section of the coats of the small intestine of a dog, showing only the commencing portions of the portal vein and the capillaries. The injection has been thrown into the portal vein, but has not penetrated to the arteries. *a*. Vessels of the villi. *b*. Those of Lieberkühn's tubes. *c*. Those of the muscular coat.

formed branches, like an artery, in the liver, and its minutest divisions (short of the capillaries) are so arranged that they divide, or, as it were, map out, the whole liver into minute nearly oval portions, or

om 1-40th to 1-20th of an inch in diameter. From these *r veins* (as they are called) proceed on every side minute , which form dense networks that seem to make up nearly substance of the lobules. Through the capillaries, the ses into *intra-lobular veins*, of which one, with its out- nches, occupies the centre, or axis, of each lobule; and a-lobular veins, by successive junction and conflux, make nks of the hepatic veins, by e blood of the portal vein, sting the bile, is carried from

Fig. 43.

Cells from the liver. Magnified.

The interspaces left in the of capillaries in every lobule er appear filled with nucleat- hepatic or bile-cells Fig. 43, se are rounded or polygonal m 1-800th to 1-1000th of an diameter, containing well- nuclei and granules, and hav- metimes, a yellowish tinge, y about their nuclei, derived from the bile, which appears st formed in them; frequently, they contain various-sized of fat (A, Fig. 43), though this fatty matter is probably of the natural constituents of healthy cells. In what rela- e cells stand to the minutest bile-ducts is unsettled: either m or line ducts, arranged in plexuses like those of the bloodvessels, and interlacing with them (Kiernan, xliii. ronenberg, lxxx. 1844, E. H. Weber, lxxx. 1844, Backer, letzius, lxxx. 1850, &c.), or else they are only *packed in* the bloodvessels, and by temporary communications dis- heir contents into the minute bile-ducts which lie in the etween the lobules (Henle, xxxvii., Handfield Jones, lxxi. ix. p. 387, &c.).[1]

what has been already said, it will appear that the blood e portal vein conveys to the liver contains portions of the parts of food absorbed by the bloodvessels during the pro- igestion. This blood of the portal vein differs, it has been , from the venous blood in other parts of the body in being pecific gravity, darker, and not capable of being rendered y the contact of salt, oxygen, or atmospheric air (Schultz, in containing only about half the ordinary quantity of

[1] e structure of the Liver, the student should read the original Kiernan (xliii. 1833, and lxxi. vol. xv.), or the description by Wilson in the Cyclopædia of Anatomy, or that in Dr. Budd's Trea- eases of the Liver. [The student is also referred to the article dy on the Structure of the Liver, in the Amer. Journ. of Med. r Jan. 1848.]

fibrine, and this in an imperfect condition, so that when it coagulates the clot forms slowly, and is less firm than in other blood; and in containing less albumen, but more red globules, and nearly twice the usual amount of fatty matter. These characteristics of portal blood refer to the composition of the blood itself, and have no reference to the extraneous substances, such as the absorbed materials of food which it may contain; neither has any complete analysis of these been made. Only, Bouchardat and Sandras (xix. Jan. 1845) state that, after herbivorous animals have been fed on farinaceous substances, more dextrine, grape-sugar, and lactic acid (?) are detected in the blood of the portal vein than in that of any other bloodvessel. Trommer, also, has detected grape-sugar in the blood of the portal vein, but not in that of the hepatic vein, in animals to whom this substance was given with their food; a fact with which we may connect that observed by Blondlot (xx. p. 62) and Chossat (xix. Oct. 1843), namely, that the administration of non-nitrogenous articles of food, especially of sugar, increases considerably the quantity of bile secreted. These things make it probable that the food, especially the saccharine and amylaceous principles, being absorbed from the intestines by the bloodvessels and conveyed through the branches of the portal vein in the liver, contributes, with the elements of the portal blood, to supply the materials out of which the bile is formed. (See page 201.)

Composition of the Bile.—The bile is a somewhat viscid fluid, of a yellow or greenish-yellow color, a strongly bitter taste, and a peculiar nauseous smell; its specific gravity is from 1026 to 1030. Its color and degree of consistence vary much apparently independent of disease; but as a rule, it becomes gradually more deeply colored and thicker while it advances along its ducts, or remains long in the gall-bladder, wherein, at the same time, it becomes more viscid and ropy from being mixed with the mucus.

The bile has been always described as having naturally a slightly alkaline reaction; but the recent investigations by Gorup-Besanez (lxxxiii.) show that in man, oxen, and pigs, it is always, when first secreted, exactly neutral; but, in the early stages of its decomposition, is apt to become acid, and subsequently alkaline.

The analysis of the bile of the ox by Berzelius (xv. art. *Galle*, p. 518), may be taken as the most nearly correct of the many that have been published. It gives

Water	904.4
Biline (with fat and coloring principles)	80.0
Mucus, chiefly from the gall-bladder	03.0
Salts	12.6
	1000.0

gations of Gorup-Besanez show that the composition of is essentially similar.

ne or *biliary matter* described by Berzelius, when freed t with which it is combined by ether, is a resinoid sub- ble in water, alcohol, and alkaline solutions, and giving ry solution the color and taste of bile. Mulder (xiv. se recent account of biline accords very closely with rzelius, describes it as being neutral, and without the unite with bases, solid but not crystallizable. Berzelius both consider biline to be a single substance, which, sition, yields various materials that have been regarded onstituents of bile, such as the biliary resin and picro- nard (xiii. t. i. p. 23), the taurine found by Gmelin, the oleic, cholinic, fellinic, and other acids of as many other According to Mulder, this decomposition of biline begins bladder of the living animal, and continues out of the the whole of the biline is decomposed; and because both ness and the variety of its results, the exact composition ine cannot be determined.

ty matter of bile consists chiefly of the crystalline sub- ned cholesterine (see p. 19). Other fatty substances found in various small proportions, such as oleine and or their acids, oleic and margaric acids, combined with soda. The *coloring matter* has not yet been obtained the bile, owing to the facility with which it is decom- occasionally deposits itself in the gall-bladder as a yellow mixed with mucus, and in this state has been frequently

Berzelius (xv. art. *Galle*) gave it the name of *chole- r bilipyrrhine*; Simon (lxxxii. p. 46, Am. Ed.) named it . Berzelius also thought it composed of two coloring ecause if, to the solution of cholepyrrhine in caustic soda, an acid is added, a green substance is deposited in flocculi, all the properties of chlorophyll, the green coloring plants; this he called *biliverdin*. After its separation, ubstance still remains, which he named *bilifulvine*. But le, as maintained by Gorup-Besanez (lxxxiii.), that these are only the products of the decomposition of a single atter, the original cholepyrrhine of Berzelius, the bili- Simon; and that the various colors presented by bile n modifications of this principle. Gorup-Besanez states, here is a considerable analogy between it and the color- of blood; a view which has been maintained also by

ncipal writers on the chemistry of the bile, besides those just Kemp, in various parts of the Chemical Gazette and London ette: Demarçay (xii. 67, p. 177); Liebig (xi. 3d edit.); Prout Am. Ed.); Griffith (cii.).

Polli (vii. 1846). The addition of a mineral acid to the coloring matter of bile produces singular transformations of tint, converting the yellowish color successively into green, blue, violet, red, and brown, and thus affords a ready means of detecting the presence of bile or of its coloring matter.

The *mucus* in bile is derived chiefly from the mucous membrane of the gall-bladder, but in part, also, from the hepatic ducts and their branches. It constitutes the residue after bile is treated with alcohol. The epithelium with which it is mixed may be detected in the bile with the microscope in the form of cylindrical cells, either scattered or still held together in layers. To the presence of this mucus is, probably, to be ascribed the rapid decomposition undergone by the biline; for, according to Berzelius, if the mucus be separated, bile will remain unchanged for many days.

The *saline* or *inorganic constituents* of the bile are similar to those found in most other secreted fluids, including the chlorides of sodium and potassium, and the phosphates and sulphates of soda, potash, lime, and magnesia. It has generally been supposed that the bile contains free soda, or an alkaline salt of this substance, such as the carbonate or tribasic phosphate; but Gorup-Besanez having shown, as already stated, that the bile is really neutral, it is probable that the carbonate and tribasic phosphate of soda found in the ashes of bile are formed in the incineration, and do not exist as such in the fluid. Oxide of iron, also, is a common constituent of the ashes of bile (Gorup-Besanez, lxxxiii.); and copper is generally found in healthy bile, and constantly in biliary calculi (Gorup-Besanez, lxxxiii.; and see p. 29).

Such are the principal chemical constituents of bile; but its physiology is, perhaps, more illustrated by its ultimate elementary composition. According to Liebig's analysis, the biliary matter—consisting of biline, and the products of its spontaneous decomposition—yields, on analysis, 76 atoms of carbon, 66 of hydrogen, 22 of oxygen, 2 of nitrogen, and a certain quantity of sulphur.[1] Comparing this with the ultimate composition of the organic parts of blood—which may be stated at $C_{36}H_{36}N_6O_{24}$ with sulphur and phosphorus—it is evident that bile contains a large preponderance of carbon and hydrogen, and a deficiency of nitrogen. The import of this will presently appear.

[1] The sulphur is combined with the taurine—one of the substances yielded by the decomposition of biline. According to Redtenbacher's analysis (x. Feb. 1846), the general correctness of which is confirmed by Dr. Gregory (vii. p. 566), the quantity of sulphur in taurine is about 26 per cent. According to Dr. Kemp (vi. No. 99, 1846), the sulphur in the bile of the ox, dried and freed from mucus, coloring matter, and salts, constitutes about 3 per cent.

process of secreting bile is probably continually going on, ars to be retarded during fasting, and accelerated on tak- . This was shown by Blondlot (xx. p. 62), who, having common bile-duct of a dog, and established a fistulous between the skin and gall-bladder, whereby all the bile se- as discharged at the surface, noticed that, when the animal ng, sometimes not a drop of bile was discharged for seve- ; but that, in about ten minutes after the introduction of the stomach, the bile began to flow abundantly, and con- do so during the whole period of digestion.

bile is probably formed first in the hepatic cells; then, scharged (in some unknown way) into the minutest hepatic ; passes into the larger trunks, and from the main hepatic ay be carried at once into the duodenum. But, probably, ppens only while digestion is going on; during fasting, it om the common bile-duct into the cystic duct, and thence gall-bladder, where it accumulates till, in the next period stion, it is discharged into the intestine. The gall-bladder ılfils what appears to be its chief or only office, that of a ir; for it enables bile to be constantly secreted, for the puri- of the blood, yet insures that it shall all be employed in the of digestion, although digestion is periodic, and the secre- bile is constant.

mechanism by which the bile passes into the gall-bladder is . The orifice through which the common bile-duct commu- with the duodenum is narrower than the duct, and appears closed, except when there is sufficient pressure behind to he bile through it. The pressure exercised upon the bile d during the intervals of digestion appears insufficient to me the force with which the orifice of the duct is closed; e bile in the common duct, finding no exit into the intestine, es the cystic duct and so passes into the gall-bladder, being ly aided in this retrograde course by the peristaltic action of cts. The bile is discharged from the gall-bladder, and enters odenum on the introduction of food into the small intestine: pressed on by the contraction of the coats of the gall-blad- d probably of the common bile-duct also; for both these contain contractile fibro-cellular tissue, with which are organic muscular fibres. Their contraction is excited by nulus of the food in the duodenum acting so as to produce movement, the force of which is sufficient to open the ori- the common bile-duct.

ous estimates have been made of the quantity of bile dis- into the intestines in twenty-four hours: the quantity s varies, like that of the gastric fluid, in proportion to the of food taken. The usual estimate has been that, in man,

the quantity of bile daily secreted is from seventeen to twenty-four ounces (xi. 1st Am. edit. p. 64); but Blondlot's investigations make it probable that this estimate is too high. The quantity discharged through the fistulous opening of the gall-bladder in one of his dogs amounted, on the average, to twelve and a half drachms in twenty-four hours. And if with Haller we suppose that the liver of man secretes from four to five times the quantity secreted by the liver of a dog, this would give from six to eight ounces as the average quantity of bile poured into the intestinal canal in twenty-four hours (xx. p. 61).

The *purposes served by the secretion of bile* may be considered to be of two principal kinds, viz., *excrementitious* and *digestive*.[1]

As an excrementitious substance, the bile is destined especially for the preparation of portions of carbon and hydrogen, in order that they may be removed from the blood: and its adaptation to this purpose is well illustrated by the peculiarities attending its secretion and disposal in the fœtus. During intra-uterine life, the lungs and the intestinal canal are almost inactive; there is no respiration of open air or digestion of food: these are unnecessary, because of the supply of well-elaborated nutriment received by the vessels of the fœtus at the placenta. The liver, during the same time, is proportionally larger than it is after birth, and the secretion of bile is active, although there is no food in the intestinal canal upon which it can exercise any digestive property. At birth, the intestinal canal is full of thick bile, mixed with intestinal secretion; for the *meconium*, or feces of the fœtus is shown, by the analyses of Simon (lxxxii. p. 572, Am. Ed.), and of Frerichs (xxii. vol. iii. p. 314), to contain all the essential principles of bile.[2] In the fœtus, therefore, the main purpose of the secretion of bile

[1] In birds, *e. g.*, in the chick, during about the last three days of incubation, the liver is made bright yellow by the absorption of the yelk, which fills and clogs all the minute branches of the portal veins. But in time the materials of the yelk disappear, part being developed into blood-corpuscles, which enter the circulation, the rest forming bile and being discharged into the intestines (E. H. Weber, xxxiii. 1846; see also an essay by him on a corresponding development of blood-corpuscles in the liver of the frog, lix. 1848, p. 38). It is possible that, in a very early period of its development, blood may be thus formed in the liver of the mammalian embryo out of the absorbed contents of its umbilical vesicle; but there is only analogy to make this probable; and there is no evidence that any such blood-making function ever belongs to the liver in extra-uterine life, or after a placenta is developed.

[2] Analysis by Frerichs:—

Biliary resin	15.6
Cholesterine, oleine, and margerine . . .	15.4
Epithelium, mucus, pigment, and salts . .	69.
	100.

must be the purification of the blood by *direct* excretion, *i. e.*, by separation from the blood, and ejection from the body without farther change. Probably, all the bile secreted in fœtal life is incorporated in the meconium, and with it discharged; and thus the liver may be said to discharge a function in some sense vicarious of that of the lungs. For, in the fœtus, nearly all the blood coming from the placenta passes through the liver previous to its distribution to the several organs of the body; and the abstraction of carbon, hydrogen, and other elements of bile will purify it, as in extra-uterine life the separation of carbonic acid and water at the lungs does.

This evident disposal of the fœtal bile by excretion makes it highly probable that the bile in extra-uterine life is also, at least for the most part, destined to be discharged as excrement. But the analysis of the feces of both children and adults shows that (except when rapidly discharged in purgation) they contain very little of the bile secreted, probably not more than one-sixteenth part of its weight, and that this portion includes only its coloring and some of its fatty matters, but none of its essential principle, the biline (Berzelius xxiv., Gorup-Besanez, lxxxiii. p. 51, Pettenkofer, x. 1844, p. 90). All the biline is again absorbed from the intestines into the blood. But the elementary composition of biline (see p. 196) shows such a preponderance of carbon and hydrogen that it cannot be appropriated to the nutrition of the tissues; therefore, it may be presumed that, after absorption, the carbon and hydrogen of the biline combining with oxygen are excreted in carbonic acid and water. The destination of the bile is, on this theory, essentially the same in both fœtal and extra-uterine life; only, in the former, it is *directly* excreted, in the latter *indirectly*, being, before final ejection, modified in its absorption from the intestines and mingled with the blood.

The change from the direct to the indirect mode of excretion of the bile may, with much probability, be connected with a purpose in relation to the development of heat. The temperature of the fœtus is maintained by that of the parent, and needs no source of heat within the body of the fœtus itself; but, in extra-uterine life, there is (as one may say) a waste of material for heat when any excretion is discharged unoxidized: the carbon and hydrogen of the biline, therefore, instead of being ejected in the feces, are reabsorbed, in order that they may be combined with oxygen, and that in the combination heat may be generated.

That ejection is the final destination of the bile, and that whatever other purposes it may serve are not essential to the maintenance of life, appear from facts mentioned by Blondlot (xx). He found that dogs may live in health for at least several months, even though the bile is prevented from passing into the intestines

by removing a portion of the common bile-duct, provided all the bile that is secreted can be discharged from the body by keeping open a fistulous communication between the skin and the gall-bladder. It must not, however, be thought indifferent whether the bile be reabsorbed or not, provided it be ejected; for, in experiments similar to those of Blondlot, Schwann (lxxx. 1844) found that the animals always died with the signs of inanition; such signs, it may be supposed, as would be produced by the deficiency of carbon and hydrogen in the blood.

Though the chief purpose of the secretion of bile may thus appear to be the purification of the blood by excretion, yet there is reason to believe that, while it is in the intestines, it serves in the process of digestion. In nearly all animals the bile is discharged, not through an excretory duct communicating with the external surface, or with a simple reservoir, as most excretions are, but is made to pass into the intestinal canal, so as to be mingled with the chyme directly after it leaves the stomach; an arrangement, the constancy of which clearly indicates that the bile has some important relations to the food with which it is thus mixed. A similar indication is furnished also by the fact that the secretion of bile is more active, and the quantity discharged into the intestines much greater, during digestion, than at any other time (Blondlot, xx. p. 62).[1] Moreover, the bile is a very elaborated fluid, formed of materials which do not pre-exist in the same condition in the blood, and secreted by cells in a highly organized gland; in which respects it resembles the higher kinds of secretions which are destined to serve some important purposes in the economy, and differs from those which, like carbonic acid and the urine, are straightway discharged from the body.

Respecting the nature of the influence exercised by the bile in digestion, there is, however, very little at present known. It is supposed that the bile assists, in some way, in converting the chyme into chyle, and in rendering it capable of being absorbed by the lacteals. For it has appeared in some experiments, in which the common bile-duct was tied, that, although the process of digestion in the stomach was unaffected, chyle was no longer well-formed; the contents of the lacteals consisting of clear colorless fluid, instead of being opaque and white, as they ordinarily are, after feeding (Sir B. Brodie, v. 1823, Tiedemann and Gmelin, xxix.). But similar experiments by Blondlet (xx.) have not yielded the same result.

It has been held, also, that the bile has the power of transform-

[1] This activity of secretion during digestion may, however, be in part ascribed to the fact that a greater quantity of blood is sent through the portal vein to the liver at this time, and that this blood contains some of the materials of the food absorbed from the stomach and intestines.

ing the saccharine principles of food into fat; but this opinion has received no satisfactory support.

The most recent observations on this subject are some made by Bernard, who has lately discovered the important fact that sugar exists in considerable quantity in the livers, not only of those animals who have had amylaceous substances in their food, but in animals which feed exclusively on flesh. The quantity of sugar which can be obtained from the liver is greatest during digestion, and is far more abundant in the blood of the hepatic than of the portal vein, and may also be found in the former when no trace of it exists in the latter, as is the case when animals are fed exclusively on animal food. This latter fact seems to prove that the sugar found in the liver is actually produced there and is not simply introduced into it by the blood entering from the intestinal canal. M. Bernard believes that the sugar is formed out of the fatty matter which is known to exist in considerable quantity in the blood of the portal vein; and his view certainly derives great support from the fact that while much fat and very little sugar enter the liver through the portal blood, very little fat and much sugar are found leaving the liver in the blood of the hepatic vein. In this production of sugar in the liver, the bile undoubtedly plays an important though as yet but ill-understood part. Perhaps the most probable view is that which supposes the fatty matter entering the liver to be resolved into its component fatty acid and glycerine (see p. 19), both of which by becoming oxidized are further transformed, the former into choleic acid to be removed by the bile, the latter into sugar removed by the blood of the hepatic vein, through which it enters the general circulation.[1]

The bile has a strongly antiseptic power, and may serve to prevent the decomposition of food during the time of its sojourn in the intestines. The experiments of Tiedemann and Gmelin show that the contents of the intestines are much more fetid after the common bile-duct has been tied than at other times; and it is found that the mixture of bile with a fermenting fluid stops or spoils the process of fermentation.

Again, the contents of the small intestines are alkaline, though the chyme is acid. The bile, with the pancreatic fluid, and the secretion of the intestinal glands, is supposed to make this acid fluid alkaline, and the bile was formerly thought to do so by the free soda, or the carbonate or tribasic phosphate of soda, said to be among its inorganic constituents; but, as already stated (p. 194), the bile is neutral, and it is more probable that, as Valentin suggests (iv. vol. i. p. 338), the chyme is made alkaline by the ammonia

[1] [For a detailed account of M. Bernard's observation, see Amer. Journ. Med. Sciences, for Oct., 1851, and Carpenter's Human Physiology, 5th edition. Art. Digestion.]

which is one of the products of the spontaneous decomposition of bile in the intestines.

The bile has also been considered to act as a kind of natural purgative [illegible]romoting an increased secretion of the intestinal glands a[illegible] stimulating the intestines to the propulsion of their contents. This view receives support from the constipation which ordinarily exists in jaundice, from the diarrhœa which accompanies excessive[illegible], and from the purgative properties of ox-gall.

The above observa[illegible]rly all that is known, and most of what is reaso[illegible] the influence of the bile on the contents of the s[illegible]ut it is evident that there is no certainty of more [illegible] fact that some influence is exercised. Noth[illegible] the changes effected by the mixture of the bi[illegible] itself, it certainly seems to produce no materia[illegible] principal elements of food; for, on submitting various substances its influence, out of the body, it has been found that starch is unchanged, that albuminous substances are unacted upon even though the bile be acidulated, and that even fatty matters undergo no chemical change, being, at the most, converted into a kind of emulsion, less perfect than that formed when similar fatty matters are mixed with the pancreatic fluid. (Bence Jones, lxxviii. July 5, 1851.) Experiments like these, however, made on bile alone, and out of the body, should be very cautiously received as evidence concerning the digestive function of this fluid when placed under natural conditions, and especially when mixed with the other secretions poured into the intestinal canal. For the observations of Zander (cxcv.) show very clearly that much more powerful effects are produced on the chyle by these several secretions when mixed than when left to act separately: and it is therefore probably to their combined rather than to their separate effect that the most important changes ensuing in the alimentary matters must be ascribed, the share which each takes in the general result being quite unknown.

Again, nothing is known with certainty respecting the changes which the reabsorbed portions of the bile undergo in either the intestines or the absorbent vessels. That they are much changed appears from the impossibility of detecting them in the blood; and that part of this change is effected in the liver (through which these portions of the reabsorbed bile must pass with all the other materials absorbed from the digestive canal) is probable from an experiment of Magendie, who found that when he injected bile into the portal vein the dog was unharmed, but was killed when he injected the bile into one of the systemic vessels.

Changes of the Food in the large Intestine.

The uncertainty respecting the changes that the chyme undergoes in the small intestine is already stated. Their general result is, that the acid chyme is made alkaline, albumen again appears, the fatty and oily matters are reduced to a state of much more minute division, so that they make the fluid look almost creamy; various gases, chiefly carburets of hydrogen, are developed, and nearly all the nutritive materials of the food, as well as of the bile and other secretions discharged into the intestinal canal, are made capable of being absorbed by either the bloodvessels or the lacteals. The process of such absorption will be described hereafter: its result is that the mixture of chyme and the various secretions is gradually made more consistent and darker, and, at the lower end of the small intestine, contains little more than the insoluble and indigestible matters, such as starch, woody fibre, horny matter, epithelium-cells and mucus-corpuscles, epidermis of both vegetable and animal tissues, crystals of ammonio-magnesian phosphates and other salts, the coloring and fatty matters of the bile, and other excrementitious substances.

The contents of the small intestine continue to be alkaline until they pass into the cæcum, when they are said to become again acid. Different explanations have been given of this acidity, and of the purposes served by it. From the abundance and size of the tubular glands in the cæcum, it has been inferred that they secrete an acid fluid somewhat similar to the gastric juice, and capable of digesting those nutritive portions of food which have escaped the influence of the gastric secretion and have passed unchanged through the small intestine. The fact that the cæcum is proportionally large in all Herbivora (except those that hybernate), supports the inference that it is an organ of special digestive properties, needed for a second or supplemental digestion of vegetable food. But respecting the acidity of the cæcum, Blondlot (xvi.) states that in many herbivorous animals and granivorous birds, as sheep, goats, pigeons, and chickens, the contents of the cæcum were never acid unless sugar in some form had been mixed with their food. He thinks that the acidity of the cæcum which then ensues is the result of that part of the starch or sugar which is not absorbed in the small intestine being transformed into lactic acid.

During the passage of the food, now becoming nearly all excrement, along the large intestine, fluid continues to be absorbed, and the mass gradually assumes the consistence and other characters of the feces expelled from the intestinal canal by the combined action of the abdominal muscles and the muscular coat of the rectum.

The length of time required for the transit of food along the in-

testinal canal is dependent on many incidental circumstances. But an estimate of the average rate may be formed from the results of experiments by Tiedemann, who found that when he tied the common bile-duct of dogs, the excrements did not appear white until two days after the operation.

The average quantity of solid fecal matter evacuated by the human adult in twenty-four hours is about five ounces. And if we take the diet-scale of [illegible] as affording a fair estimate of the quantity of solid [illegible] by an individual in the same time, viz., from 3[illegible] to [illegible] (v. p. 489, Am. Ed.), it will follow that from [illegible] solid nutriment are absorbed into the system [illegible] five ounces consist almost entirely of insol[illegible]matter.

According to [illegible]us (xxiv. p. 268), which is adopted by Simo[illegible] Ed.) human feces of consistence sufficient to f[illegible] are composed of

Water		75.3
Matters soluble in water	Bile 0.9	
	Albumen 0.9	
	Peculiar extractive 2.7	
	Salts 1.2	5.7
Insoluble residue of the food		7.0
Insoluble matters which are added in the intestinal canal, —mucus, biliary resin, fat, and a peculiar animal matter		14.0
		102.0

The ashes of the human feces have been analyzed by Enderlin (x. 1844), who found that 100 parts yielded

Chloride of sodium and alkaline sulphate	1.367
Tribasic phosphate of soda	2.633
Phosphate of lime and phosphate of magnesia	81.372
Phosphate of iron	2.091
Sulphate of lime	4.564
Silica	7.973
	100·000

Movements of the Intestines.

It remains only to consider the manner in which the food and the several secretions mingled with it are moved through the intestinal canal, so as to be slowly subjected to the influence of fresh portions of intestinal secretion, and as slowly exposed to the absorbent power of all the villi and bloodvessels of the mucous membrane. Their movement is *peristaltic* or *vermicular*, effected by the alternate contractions and dilatations of successive portions of the intestinal coats. The contractions, which may commence at any point of the intestine, extend in a wave-line manner along the

any given portion the longitudinal muscular fibres con-
or more than the circular; they draw a portion of intes-
ds, or, as it were, backwards, over the substance to be
and then the circular fibres of the same portion con-
succession from above downward, or, as it were, from
wards, press on the substance into the portion next
which, at once, the same succession of actions next en-
ese movements take place slowly, and, in health, are
unperceived by the mind; but they are perceptible when
ccelerated under the influence of any irritant.
ovements of the intestines are sometimes retrograde or
altic; and there is no hindrance to the backward move-
ne contents of the small intestine. But complete security
l against the passage of the contents of the large into the
stine, by the ileo-cæcal valve, an apparatus in which are
the principles of construction observed in the valves of
els and in that of the pylorus. For it consists, essen-
two wide semilunar folds of mucous membrane, which
om the end of the ileum into the cavity of the cæcum,
o placed, that when any of the contents of the cæcum are
ack on them, they will first approximate their edges, and
ss them together, and hold them close like the valves of
But, besides, the orifice of communication between the
d cæcum (at the borders of which orifice are these folds
is membrane) is encircled with muscular fibres, the con-
of which prevents the undue dilatation of the orifice.
ding from above downwards, the muscular fibres of the
stine become, on the whole, stronger in direct proportion
reater strength required for the onward moving of the
ich are gradually becoming firmer. The greatest strength
rectum, at the termination of which a *sphincter* muscle
, outside the longitudinal fibres, and holds the orifice close
tant slight contraction under the influence of the spinal

eculiar condition of the sphincter, in relation to the
ystem, will be again referred to. The rest of the intesti-
is under the direct influence of the sympathetic or gan-
stem, and, indirectly or more distantly, is subject to the
of the brain and spinal cord. Experimental irritation of
or cord produces no evident or constant effect on the
ts of the intestines: yet, in consequence of certain condi-
he mind, the movements are accelerated or retarded, and
gia the intestines appear, after a time, much weakened in
er, and costiveness and tympanitis ensue. Irritation of
is of the sympathetic connected with any portion of in-
ay excite contraction of that portion; and, if a small

portion of intestine be irritated, the consequent movement is extensive, slow, regular, and orderly, like all that ensue when an irritation, before it acts on muscular fibres, is conveyed to a nervous centre, such as a ganglion, and thence reflected.

CH[illegible]K.

THE process of absorpti[illegible]ne of its objects the introduction into the blood of [illegible]ls from the food and air, and whatever comes into c[illegible]e external or internal surfaces of the body; and, for another, [illegible] taking away of parts of the body itself, when, having fulfilled their office, or for any other reason, they need to be renewed. In both these offices, i. e., in both absorption from without and absorption from within, the process manifests some variety, and a very wide range of action; and in both it is probable that two sets of vessels are or may be concerned, namely, the bloodvessels, and the lacteals or lymphatics, to which the term absorbents has been especially applied.

The *lymphatics* are distributed in nearly all the parts of the body that contain bloodvessels, and convey a fluid termed *lymph*; the lacteals are confined exclusively to the intestinal canal, and at certain times contain the *chyle*. The difference between these two sets of vessels is more apparent than real; in structure they are nearly identical; they have a common trunk, the thoracic duct; and, for their contents, the chyle probably differs from the lymph only in that it contains, besides the lymph derived from the walls of the intestines as from other parts, certain elements of food absorbed through the intestinal villi, which give it a characteristic milky whiteness.

Absorption by the lacteals has been commonly described as *nutritive absorption*, because materials for nutrition are, by its means, conveyed into the blood; while absorption by the lymphatics has been more generally named *interstitial absorption*, and regarded merely as the means by which the several parts of the body are cleared of their waste and excrementitious materials, whether during growth or in common nutritive repair. But it is most probable that the latter purpose is effected by the absorption by bloodvessels; and that the lymphatics are in this again essentially similar to the lacteals, that they absorb and elaborate organizable principles, capable of being employed for further purposes in the economy.

Absorption by the Lacteal Vessels.

g the passage of the chyme along the whole tract of the l canal, its completely digested parts are absorbed by the ıels and lacteals distributed in the mucous membrane. dvessels appear to absorb none but the dissolved portions od, and these they imbibe without choice; whatever can the blood passes into the vessels, as will be presently l. But the lacteals appear to absorb only certain constit- the food, including particularly the fatty portions. The n by both sets of vessels is carried on most actively, but nsively, in the villi of the small intestine; for in these processes both the capillary bloodvessels and the lacteals ght almost into contact with the intestinal contents.

s been already stated (p. 189) that the villi of the small s are minute vascular processes of mucous membrane, each ng a delicate network of bloodvessels, and a network of , and usually invested by a sheath of epithelium. In the ces of the mucous membrane between the villi, as well as l the rest of the intestinal canal, the lacteals and blood- are also densely distributed in a close network (E. H. , lxxx. 1847); the lacteals, however, being more sparingly d to the large than to the small intestine.

as long been, and is still, very difficult to explain how ab- n by the lacteals is effected. It was supposed that both the s and the villi were perforated at their extremities, and that the tion took place through the orifices: but there are no such .; the walls of the lacteals, like those of the bloodvessels, are here complete and closed. From the fact that the bloodves- villi lie external to the lacteals, and hold nearly the same n to them as in some secernent glands they do to the extre- of the gland-ducts, Valentin (iii. p. 142) was led to suggest ıe chyle cannot be immediately transferred from the intestine lacteal vessels, but is absorbed first by the bloodvessels and as it were, secreted into the lacteals. More recent investiga- ıave in a measure justified this view, by making it probable ıe abstraction of the elements of chyle from the intestine, and ransference into the lacteals, are effected through the instru- lity of cells, which derive at least part of their means of sub- e from the bloodvessels of the villi. The observations of ir (ii. p. 4), E. H. Weber (lxxx. 1847), and Kiiss (xxvii. 1846), have shown that, in the tissue situated between the ı of the capillary bloodvessels and the lacteals of the villi, cells are developed at each period of digestion, and that nlarge and become filled, some with opaque white contents, ıers with a transparent oily-looking fluid (Weber). In

Goodsir's opinion, the cylindrical epithelium investing the villi is cast off at each period of digestion, and the naked villi thus come into direct contact with the contents of the intestine. Meanwhile the cells within them, as they enlarge, absorb materials from the surrounding chyme, which they elaborate in their interior, and then discharge, by their rupture or solution, either into or around the lacteals. But E. H. Weber believes that the epithelial cells, instead of being shed during digestion, are the agents by which the chyle is first taken up from the intestinal canal; and that from these it is transferred to other cells within the villi, by which it is finally conveyed to the lacteals. Küss seems to entertain a similar view (see Gerber and Delafond, xviii. Juin, 1843). Whether or not the epithelium is concerned in the process of absorption, it appears probable that the proper cells of the villi are essential to the elaboration and its conveyance into the lacteals; and from the fact that these cells contain an opaque while others contain a transparent fluid, it may, perhaps, be assumed that they possess the power of absorbing different materials.

The introduction of cells, for the elaboration of the fluid previous to its passing into the lacteals, sufficiently explains the power which these vessels seem to possess of selecting the materials to be absorbed by them. Numerous experiments (which will be again referred to in connection with the absorption by bloodvessels) have shown that when various odorous, coloring, and saline matters are introduced into the intestines, they pass into the bloodvessels, but not into the lacteals; these, we may believe, being guarded from their entrance by the network of bloodvessels around them, and by the elaborating cells.

Absorption by the Lymphatics.

The vessels for the absorption of lymph are distributed in nearly all parts of the body. Their existence has not yet been determined in the brain and spinal cord, the bones, cartilages, dense tendons, the eye, placenta, umbilical cord, membranes of the ovum, or any of the non-vascular parts, as the nails, cuticle, hair, and the like (xxv. 1842, p. 45). But it is probable that they exist in all the other parts that have bloodvessels.

The lymphatics commence either in closely-meshed networks, interspersed among the proper elements and bloodvessels of the several tissues, the size of the meshes and the width of the canals varying like those of the capillary bloodvessels (Figs. 44 and 45); or else in pointed closed tubes or processes from the vessels, such as are shown in the annexed sketch of the lymph- and bloodvessels in a part of the tail of the tadpole (Fig. 46.) In this state many of the origins of the lymphatics communicate with pointed or star-

shaped cells; but this may be peculiar to the embryonic state, for no similar cells are seen in the adult, neither is there any appearance

Fig. 44.

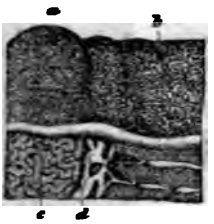


Fig. 45.

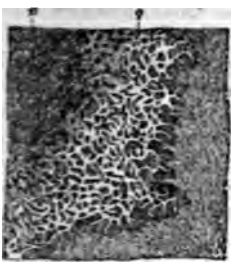


Fig. 46.

Fig. 44. Lymphatics of the glans penis, and prepuce, after Breschet. *a*, Superficial layer of lymphatics on the glans; *b*, the same on the prepuce; *c*, deep layer on the glands; *d*, large lymphatics surrounding the base of the glans.

Fig. 45. Lymphatics of the mucous membrane of the stomach, after Breschet. *a*, Superficial layer; *b*, deep layer.

Fig. 46. Capillary bloodvessels and lymphatics from the tail of the tadpole: showing the origin of the lymphatics from radiated cells and by pointed processes. The bloodvessels are denoted by the corpuscles they contain.

of the existence of cells for the elaboration of lymph similar to those described in the villi.

It has been supposed that the lymphatics at their origin and in the substance of absorbent glands communicate directly with the bloodvessels, but there is not sufficient evidence for believing that this is ever the case in Mammalia and birds, although it may be so in Amphibia and fish (xxv. 1842, p. 45). In man and Mammalia, the lymphatics and bloodvessels are connected only by the principal lymphatic trunk, the thoracic duct, which opens into the junction of the left internal jugular and subclavian veins, and by a corresponding but smaller trunk, which pours its contents into the corresponding part on the right side.

The real nature of the substances absorbed by the lymphatic

vessels, and the mode in which the absorption is effected, are still among the enigmas of physiology. It may, however, be held as highly probable that the materials which it is the special office of the lymphatics to absorb, are, like those commonly absorbed by the lacteals, chiefly of a nutritive kind, capable of higher organization and of contributing to the nutrition of the body. Whether these are derived exclusively from the liquor sanguinis effused for the nutrition of the tissues, or from the fluid with which the tissues are kept moist, or in part from regenerated or used portions of the tissues, cannot be determined. Parts which, having entered into the composition of a tissue, and having fulfilled their purpose, are removed, may not be altogether excrementitious. They may undergo reorganized and adapted to the nutrition of the lower tissue: and these may be absorbed. On the whole, however, it is most probable that they are derived from the liquor sanguinis; since changes in the former usually correspond very closely with changes in the character of either the whole mass of blood, or of that in the vessels of the part from which the lymph is examined. Thus Herbst (cxxxiv.) found that the coagulability of the lymph is directly proportionate to that of the blood; and that when fluids are injected into the bloodvessels in sufficient quantity to distend them, the injected substance may be almost directly afterwards found in the lymphatics.

Properties of Chyle and Lymph.

The fluid contained in the lacteals during fasting is clear and transparent, and differs in no respect from ordinary lymph; but during absorption from the chyme, it becomes milky, and acquires the other characters of chyle.

The whiteness and opacity of chyle is due to the presence of innumerable particles of oily or fatty matter, of exceedingly minute, though nearly uniform, size, measuring on the average about 1-30,000th of an inch (Gulliver, xxviii. p. 82, *note*). These constitute what Mr. Gulliver appropriately terms the *molecular base* of chyle. Their number, and consequently the opacity of the chyle, are dependent upon the quantity of fatty matter contained in the food. Hence, as a rule, the chyle is whitest and most turbid in carnivorous animals; less so in Herbivora; while in birds it is usually transparent. The fatty nature of the molecules is made manifest by their solubility in ether, and, when the ether evaporates, by their being deposited in various-sized drops of oil.[1] Yet, since they do not run together and form a larger drop, as particles of oil

[1] Some of the molecules may remain undissolved by the ether; but this appears to be due to their being defended from the action of the ether by being entangled within the albumen which it coagulates.

would, it appears very probable that each molecule consists of oil coated over with albumen, in the manner in which, as Ascherson (lxxi. 1840) observed, oil always becomes covered when set free in minute drops in an albuminous solution. And this view is supported by the fact that when water or dilute acetic acid is added to chyle, many of the molecules are lost sight of, and oil-drops appear in their place, as if the investments of the molecules had been dissolved, and their oily contents had run together.

Except these molecules, the chyle taken from the villi, or from lacteals near them, contains no other solid or organized bodies. The fluid in which the molecules float is albuminous, and does not spontaneously coagulate, though coagulable by the addition of ether. But as the chyle passes on towards the thoracic duct, and especially while it traverses one or more of the mesenteric glands (propelled by forces which will be described with the structure of the vessels), it is elaborated. The quantity of molecules and oily particles gradually diminishes; cells, to which the name of chyle-corpuscles is given, are developed in it; and, by the development of fibrine, it acquires the property of coagulating spontaneously. The higher in the thoracic duct the chyle advances, the more is it, in all these respects, developed, the greater is the number of chyle-corpuscles, and the larger and firmer is the clot which forms in it when withdrawn and left at rest. Such a clot is like one of blood, without the red corpuscles; having the chyle-corpuscles entangled in it, and the fatty matter forming a white creamy film on the surface of the serum. But the clot of chyle is softer and moister than that of blood. Like blood, also, the chyle often remains for a long time in its vessels without coagulating, but coagulates rapidly on being removed from them (Bouisson, xix. 1844). The existence of fibrine in it is, therefore, certain; its increase appears to be commensurate with that of the corpuscles; and like them it is not absorbed as such from the chyme (for no fibrine exists in the chyle in the villi) but is gradually elaborated out of the albumen which chyle, in its earliest condition, contains.

The structure of these chyle-corpuscles was described when speaking of the white or rudimentary corpuscles of the blood, with which they are identical (see pp. 52 and 63). Their mode of origin is obscure. It is possible that they are formed, as has been supposed, by an aggregation of some of the particles composing the molecular base of chyle; but such particles do not exist in lymph, in which, however, abundant corpuscles identical with those of chyle-corpuscles are found.

Lymph, under ordinary circumstances, is clear, transparent, and colorless, or of a pale yellow tint. It is devoid of smell, is slightly alkaline like chyle, and has a saline taste. As seen with the

microscope in the small transparent vessels of the tail of the tadpole, the lym lly contains no corpuscles or particles of any kind, and it is ly only in the larger trunks, in which, by a process similar to escribed in the chyle, the lymph is more elaborated, that any corpuscles are formed. These corpuscles are already described; they are similar to those in the chyle, but less numerous. The fluid in which the corpuscles float is commonly, and in health, albuminous, and contains icles or molecular base; but is liable to variations general state of the blood, and that of the organ e lymph is derived. As it advances towards t d passes through the lymphatic glands, it be ontaneously coagulable from the formation of fib

From what has ppear that perfect chyle and lymph are, in esse early similar, and scarcely differ, except in th fatty matter in the chyle. The comparative an luids obtained from the lacteals and the lymphatics of a donkey, is thus given by Dr. Owen Rees (lxxi. Jan. 1841).

	Chyle.	Lymph.
Water	90.287	96.536
Albumen	3.516	1.200
Fibrine	0.370	0.120
Animal extractive	1.565	1.559
Fatty matter	3.601	a trace.
Salts	0.711	0.585
	100.000	100.000

The analyses of Nasse afford an estimate of the relative compositions of the lymph, chyle, and blood of the horse.[1]

	Lymph.	Chyle.	Blood.
Water	950.	935.	810.
Corpuscles		4.	92.8
Albumen	89.11	81.	80.
Fibrine		0.75	2.8
Extractive matter	4.88	6.25	5.2
Fatty matter	0.09	15.	1.55
Alkaline salts	5.61	7.	6.7
Phosphate of lime and magnesia, oxide of iron, &c.	0.31	1.	0.95
	1000.	1000.	1000.

[1] The analysis of the blood differs rather widely from that given at pages 54–5; but though it be erroneous, it is probable that corresponding errors exist in the analysis of the lymph and chyle, and that therefore the tables in the text may represent accurately enough the relation in which the three fluids stand to each other.

ıtents of the thoracic duct, including both the lymph and
ed, in an executed criminal, were examined by Dr. Rees,
d them to consist of 90.48 per cent. of water, 7.08 of
and fibrine, 0.108 of extractive, 0.92 of fatty, and 0.44
matter.

ll these analyses of lymph and chyle, it appears that they
ssentially the same constituents as are found in the blood,
men, fibrine, and fatty matter, the same saline substances,
. Their composition differs from that of the blood in
ther than in kind; they contain a less proportion of all
tances dissolved in the water (see Nasse's analyses, just
and much less fibrine. The fibrine of lymph, besides
s in quantity, appears to be in a less elaborated state than
he blood, coagulating less rapidly and less firmly. These
es gradually diminish, while the lymph and chyle, passing
and through the thoracic duct, gradually approach the
which they are to be mingled with the blood. For, in the
duct, besides the higher and more abundant development
ibrine, the lymph- and chyle-corpuscles are found more
l towards their development into red blood-corpuscles;
es even that development is completed, and the lymph has
h tinge from the number of red blood-corpuscles that it

.

general result, therefore, of both the microscopic and the
l examinations of the lymph and chyle, demonstrate that
rudimental blood; their fluid part being like the liquor
s diluted, but gradually becoming more concentrated; and
rpuscles being in process of development into red blood-
es. Thus, in quality, the lymph and chyle are adapted to
ı the blood; and their quantity, so far as it can be esti-
ppears ample. In one of Magendie's experiments, half an
f chyle was collected, in five minutes, from the thoracic
a middle-sized dog; Collard de Martigny obtained nine
f lymph, in ten minutes, from the thoracic duct of a rab-
h had taken no food for twenty-four hours; and Geiger
ee to five pounds of lymph daily from the foot of a horse,
om the same quantity had been flowing several years with-
ry to the health. Bidder (lxxx. 1845) has found, on
the thoracic duct in cats, immediately after death, that the
lymph and chyle continued to flow from one to six min-
d from the quantity thus obtained, he estimated that if the
of the thoracic duct continued to move at the same rate,
ıtity which would pass into a cat's blood in twenty-four
ould be equal to about one-sixth of the weight of the whole
ınd, since the estimated weight of the blood in cats is to the
their bodies as 1 : 5.7, the quantity of lymph daily travers-

ing t[illegible]et would appear to be about equal to the quantity of b[illegible]e contained in the animals. By another series of experim[illegible]dder estimated that the quantity of lymph traversing th[illegible]e duct of a dog in twenty-four hours, is about equal to two-thirds of the blood in the body. If we take these estimates, it will not follow from them that the whole of an animal's blood is daily replaced by the development of lymph and chyle; for even if th[illegible]h and chyle daily formed be equal to that of th[illegible] contents of the blood will be much too great to[illegible]e of the lymph and chyle. According to Nasse's[illegible]he solid matters of a given quantity of blood c[illegible]l out of less than three or four times the quan[illegible]hyle.

Office of the L[illegible]ic Vessels and Glands.

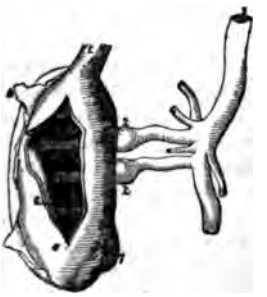
The lacteal and l[illegible]re not only to contain but to move the chyle and lymph. In structure they are very like veins; having, according to Kölliker, an external coat of fibro-cellular tissue, with elastic filaments; within this a thin layer of fibro-cellular tissue, with organic muscular fibres, which have, principally, a circular direction, and are much more abundant in the small than in the larger vessels; and again, within this an inner elastic layer of longitudinal fibres, and a lining of epithelium; and numerous valves. The valves, constructed like those of veins, and with their free edges turned towards the heart, are usually arranged in pairs, and, in the small vessels, are so closely placed, that, when the vessels are full, the valves constricting them, where their edges are attached, give them a peculiar braided or knotted appearance (Fig. 44, p. 209; and Fig. 48, p. 217).

With the help of the valvular mechanism, all occasional pressure on the exterior of the lymphatic and lacteal vessels propels the lymph towards the heart: thus muscular and other external pressure accelerates the flow of the lymph as it does that of the blood in the veins (see p. 111). The actions of the muscular fibres of the small intestine thus seem to assist in propelling the chyle: for, in the small intestine of a mouse, Poiseuille saw the chyle moving with intermittent propulsions that appeared to correspond with the peristaltic movements of the intestine. But, for the general propulsion of the lymph and chyle, it is probable that, together with the *vis à tergo* resulting from absorption (as evidenced in the ascent of sap), and from external pressure, much of the force is derived from the contractility of the vessel's own walls. Kölliker, after watching the lymphatics in the transparent tail of the tadpole, states that no distinct movements of their walls can ever be seen, but that as they are emptied after death they gradually contract, and then, after some time, again dilate to their former size, exactly as the

do under the like circumstances (xxxi. 1846, p. 99). e larger vessels, in the human subject, commonly lves after death; so that, although absorption is pro- going on just before the time of death, it is not com- ıe lymphatic or lacteal vessels full. Their power of nder the influence of stimuli has been recently de- r Kölliker, who applied the wire of an electro-magnetic ıome well-filled lymphatics on the skin of a boy's foot, ı removal of his leg by amputation, and noticed that the vessels diminished at least one-half (cxc. July s most probable that this contraction of the vessels ; life, and that it consists, not in peristaltic or undu- ıents, but in an uniform contraction of the successive ıe vessels, by which pressure is steadily exercised upon s, and which alternates with their relaxation.

and some birds, an important auxiliary to the move- lymph and chyle is sup- ain muscular sacs, named (Fig. 47). The number of these organs vary. In ds there are usually four, and two posterior; in the erior lymph-heart on each ed in the ischiadic region the skin; the anterior lies ver the transverse process . vertebra. Into each of ı several lymphatics open; f the vessels being guarded ıich prevent the retrograde e lymph. From each heart . proceeds and conveys the ly into the venous system. he inferior lymphatic heart, s, pours its lymph into a he ischiadic vein; by the ı lymph is forced into a the jugular vein; which its anterior surface, and ıes turgid each time that acts. Blood is prevented ; from the vein into the art by a valve at its orifice.

Fig. 47.



Lymphatic heart (9 lines long, 4 lines broad) of a large species of serpent, the Python bivittatus, after E. Weber. 4. The external cellular coat. 5. The thick muscular coat. Four muscular columns run across its cavity, which communicates with three lymphatics (1—only one is here seen), with two veins (2, 2). 6. The smooth lining membrane of the cavity. 7. A small appendage, or auricle, the cavity of which is continuous with that of the rest of the organ.

ılar coat of these hearts is of variable thickness: in can only be discovered by means of the microscope; case it is composed of transversely-striated fibres.

The contraction of the hearts are rhythmical, occurring abou
times in a minute, slowly, and, in comparison with those
blood-hearts, feebly. The pulsations of the cervical pair a
always synchronous with those of the pair in the ischiadic
and even the corresponding sacs of opposite sides are not
synchronous in their action (Müller, xxxii. p. 275, Am. Ed.

Unlike the contractions of the blood-heart, those of the l
heart are directly dependent upon a certain limited portion
spinal cord. For Volkmann (lxxx. 1844) found that so l
the portion of spinal cord corresponding to the third verte
the frog was uninjured, the cervical pair of lymphatic heart
tinued pulsating, after all the rest of the spinal cord and the
was destroyed; while destruction of this portion, even thou
other parts of the nervous centres were uninjured, instan
rested the heart's movements. The posterior or ischiadic
lymph-hearts were found to be governed, in like manner,
portion of spinal cord corresponding to the eighth vertebra
vision of the posterior spinal roots did not arrest the mover
but division of the anterior roots caused them to cease at on

The Glands placed on the lacteal and lymphatic vessels
essentially of plexuses of the vessels; but, together with the v
most of them contain corpuscles, by the action of which, af
plan of gland-cells, it is probable that the lymph or chyle is
fied, and its development assisted.

Each gland has an investing capsule of cellular tissue
which prolongations dip into its substance forming part
Into each gland two or three vessels enter, which are named
ent vessels; as they enter, their coats are thinned, their e
coat separating and becoming continuous with the capsule
gland (Goodsir, ii. p. 44). Thus, having only their intern
and epithelium, they pass into the gland, and therein subdi
running tortuously, variously dilated and anastomosing, the
a plexus. The vessels of the plexus, converging and uniting
two or more *efferent vessels*, which are rather larger than the a
ones, and issuing from the glands receive again their externa
and proceed on their way towards the thoracic duct. No ly
tic or lacteal joins the thoracic duct without thus passing th
one or more such glands.

Capillary bloodvessels are abundantly distributed betwe
perhaps, more properly, upon the walls of, the lymph-ves
the glands; so that the blood is here brought into as close r
with the lymph or chyle, as, in a secreting gland, it is wi
ducts and their contents (Fig. 48). Moreover, either with

[1] *See also* on the whole subject Stannius, lxxx. 1843; Panizz
1834, p. 300; E. Weber, lxxx. 1835, p. 535; and Valentin, xxxiv. B

lymph-vessels (as Goodsir thinks) or between them, grouped in cells like the acini of secreting glands or the sacculi of Peyer's glands, there are, in all the more perfect lymphatic glands, abundant minute corpuscles, nuclei, or cytoblasts. These (which have been often named lymph-corpuscles, and confounded with those properly so called and already described) are spheroidal, or disk-shaped, pellucid particles, about 1-3000th of an inch or less in diameter, of simple structure, but having two or three minute, dark particles like nucleoli in them. They are very like the corpuscles of the thymus and thyroid glands, which will be hereafter described.

Fig. 48.

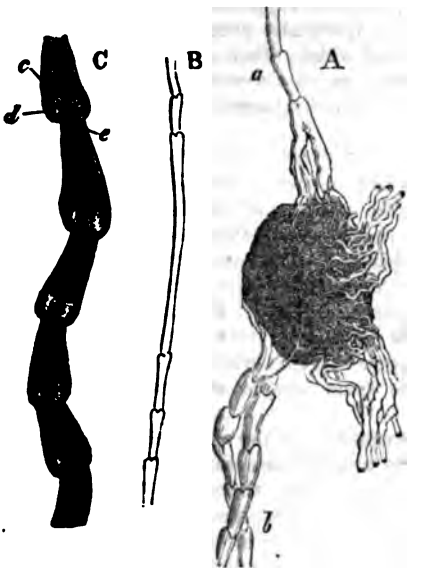


Fig. 48. A. One of the inguinal lymphatic glands injected with mercury. *a*. Afferent lymphatic vessel from the lower extremity. *b*. Efferent vessel. Others are also seen.

B. One of the superficial lymphatic trunks of the thigh.

C. One of the femoral lymphatic trunks laid open longitudinally to display the valves within it. *c*. Sinus between the valve and the wall of the vessel. *d*. Surface of one valve, directed towards the opposite. *e*. Semicircular attached margin of the valve. After Mascagni.

The fact that in fish and Amphibia mere plexuses of lymphatics occupy the places of the lymphatic glands of the warm-blooded classes, *may indicate that some* mechanical and chief purpose is

served by the glands as plexuses; but no such purpose can be discerned.

The close p[illegible]ximity between the bloodvessels and the lymphatics in the glands [illegible]as been thought to be provided in order that some of the constituents of the blood may be added to the lymph; and the increase of fibrine in the lymph and chyle, after they have traversed glands, has been thus explained. But this may be as well explained by the [illegible]velopment of the two fluids; and, on the whole, it [illegible]robable that the glandular office of these orga[illegible]y the instrumentality of the dotted corpuscles. [illegible]om what appears to be the office of correspondi[illegible]e secreting glands and glands without ducts, may be [illegible]erive, from the blood in the capillaries of the l[illegible]aterials which they elaborate as they grow, and [illegible]ated, are discharged into the lymphatic vessels, [illegible]and, the elaborated contents of the gland-cells are discharged [illegible]he gland-ducts.

Absorption by the Bloodvessels.

The process thus named is that which has been commonly called *absorption by the veins;* but the term here employed seems preferable, since, though the materials absorbed are commonly found in the veins, this is only because they are carried into them with the circulating blood, after being absorbed by all the bloodvessels (but chiefly by the capillaries) with which they were placed in contact. There is nothing in the mode of absorption by bloodvessels, or in the structure of veins, which can make them more active than arteries of the same size, or so active as the capillaries, in the process.

In the absorption by the lymphatics or lacteal vessels just described, there appears something like the exercise of choice in the materials admitted into them; for the chyle and lymph have a nearly constant composition; and we must admit, as an hypothesis, either that these vessels are so constructed that only certain materials, capable of being assimilated to their proper contents, can traverse their walls, or else, that the materials from which the perfect chyle and lymph are to be developed, are secreted into the lacteals and lymphatics from the adjacent bloodvessels. In either hypothesis, we assume something which brings the absorption by lacteals, and lymphatics into the category of vital processes. But the absorption by bloodvessels presents no such appearance of selection of materials; rather, it appears that every substance, whether gaseous, liquid, or a soluble or minutely divided solid, may be absorbed by the bloodvessels, provided it is capable of permeating their walls, and of mixing with the blood; and that of all such substances the mode and measure of absorption are determined

solely by their physical properties and conditions, and by those of the blood and the walls of the bloodvessels.

While the question was being discussed, whether absorption (using the term generally) were effected by the lymphatics or the veins, many experiments were performed to demonstrate the fact of absorption by the bloodvessels, which may be quoted, not only as evidence for that fact, but in illustration of the difference between the absorption by lymphatics, and that by bloodvessels, in regard to the materials they severally receive and convey into the circulation.

Various odorous and saline matters taken with the food, or injected into the intestines of an animal, are soon found in the blood of the vena portæ, or other bloodvessels, or in the urine, but are not found in the chyle; or, if found there, not till they may have passed into the lacteals from their bloodvessels. This is shown by numerous experiments, especially by those of Tiedemann and Gmelin, and Panizza. The substances used in the experiments were ferrocyanate of potash, sulphate of potash, several salts of lead, iron, and other metals, indigo, madder, rhubarb, camphor, musk, alcohol, turpentine, &c. Mayer (xcvi. t. iii. p. 485), also, when he injected ferrocyanate of potash into the lungs, found it in the left side of the heart sooner than in the right; showing that it had taken the course of the blood, not of the lymph, which would have carried it to the right side of the heart first. All these substances, therefore, appear to be absorbed by bloodvessels exclusively.

Again, if any of these substances be included within a portion of an animal's intestine tied at both ends, and if all the vessels of that portion of the intestine be cut away, except its artery and vein, the substances, being absorbed, will be found in the blood of the vein; but, if the main arteries and veins be tied, and the lacteals left entire, the same substances will not be found in them. So, with poisons, such as opium and strychnia, in the experiments of Magendie (cxxxiii. p. 345, Am. Ed.) and Segalas (lxii. t. ii. p. 117). When one of these poisons was put into a piece of intestine, of which the lacteals were tied, but the bloodvessels were free, poisoning took place within six minutes after returning the intestine into the abdomen; but if the vein or veins of the piece of intestine were tied, so as to stop the circulation of blood, the effects of the poison were delayed for an hour or more, though the lacteals were free to absorb and carry it to the blood. The numerous experiments, proving that poisons are not absorbed, or only very slowly, after insertion into the hinder extremities of animals, in whom the aorta or vena cava inferior is tied, tend to the same conclusion, that these are among the substances not absorbed by the lymphatic or lacteal vessels, but absorbed without choice by the bloodvessels.

It is probably a general truth that, in parts which are supplied

with both bloodvessels and lymphatics, the lymphatics (or lacteals for the intestines) absorb only such materials as will form lymph and chyle for the replenishing of the blood, while the bloodvessels absorb all other materials, and such substances as are accidentally brought into contact with them. But in parts which receive only bloodvessels, such as the brain and spinal cord, the eye and placenta, and probably most of the bones, cartilages, and fibrous tissues, the bloodvessels [illegible] form the whole function of absorption, as they do [illegible] e animals.

The absorption by [illegible] the consequence of their walls being, like all ou[illegible] e body, porous and capable of imbibing fluids, [illegible] d being so composed that most fluids will mingl[illegible] process of absorption, in an instructive tho[illegible] legree, may be observed in any portion of vas[illegible] from the body. If such a one be placed in a ves[illegible] shortly swell, and become heavier and moister, through the quantity of water imbibed or soaked into it; and if, now, the blood contained in any of its vessels be let out, it will be found diluted with water, which has been absorbed by the bloodvessels and mingled with the blood. The water round the piece of tissue, also, will become blood-stained; and, if all be kept at perfect rest, the stain derived from the solution of the coloring matter of the blood (together with which chemistry would detect some of the albumen and other parts of the liquor sanguinis) will spread more widely every day. The same will happen if the piece of tissue be placed in a saline solution instead of water, or in a solution of coloring or odorous matter, either of which will give their tinge or smell to the blood, and receive in exchange the color of the blood.

Even so simple an experiment will illustrate the absorption by bloodvessels during life: the process it shows is imitated, but with these differences; that, during life, as soon as water or any other substance is admitted into the blood, it is carried from the place at which it was absorbed into the general current of the circulation; and that the coloring matter of the blood is not dissolved so as to ooze out of the bloodvessels into the fluid which they are absorbing. The absorption of gases by the blood may be as simply imitated. If venous blood be suspended in a moist bladder in the air, its surface will be reddened by the contact of oxygen, which is first dissolved in the fluid that moistens the bladder, and is then carried in that fluid to the surface of the blood; while, on the other hand, watery vapor and carbonic acid will pass through the membrane and be exhaled into the air.

In all these cases, alike, there is a mutual interchange between the substances; while the blood is receiving water it is giving out its coloring matter and other constituents: or, while it is receiving oxygen it is giving out carbonic acid and water; so that, at the end

of the experiment, the two substances employed in it are mixed; and if, instead of a piece of tissue, one had taken a single bloodvessel full of blood and placed it in water, both blood and water would, after a time, have been found both inside and outside the vessel.

It is perhaps to be regretted that the phenomena just described should have received the names of *Endosmosis* and *Exosmosis;* since the use of such terms may seem to imply that peculiar properties and forces are engaged in a process which really appears to be due only to the power which porous substances have of absorbing liquids by capillary attraction, and to the force with which liquids or gases brought into contact tend to mix with one another. If, in the case supposed of a bloodvessel filled with blood and placed in water, one were to determine accurately the quantity of water that passed to the blood and that of blood that passed to the water, he would find the former always greater than the latter. And so with other substances; it would almost always happen that if the two fluids placed on opposite sides of a membrane were of different densities or specific gravities, a larger quantity of the less dense fluid would pass into the more dense, than of the latter into the former. M. Dutrochet, who made the earliest and best scientific investigation of this subject, having used in his experiments an apparatus in which it was most convenient to allow the less dense fluids to pass into the more dense, employed the term *Endosmosis* to express the inward current, and *Exosmosis* for the outward one; and these terms, though they imply only the direction in which one or other of the two mixing fluids may happen to move in an experiment, are now used, the first as the name of the more rapid, the second as that of the less rapid, stream. The instrument employed by M. Dutrochet was named an Endosmometer (Fig. 49). It may consist of a graduated tube expanded into a bell at one end, over which a portion of membrane may be tied. If, now, the bell be filled with a fluid of much density, such as a strong solution of salt, and be immersed in one of less density, as water, the water will endosmose or pass into the solution, more rapidly than the solution will exosmose or pass out; but if the water were put in the bell and the saline solution outside, the directions of the currents would be reversed, and the names falsified; but the fact would remain the same, that the less dense would pass in a more rapid current than the more dense, till the two fluids were equally mixed on both sides of the membrane.

Fig. 49.

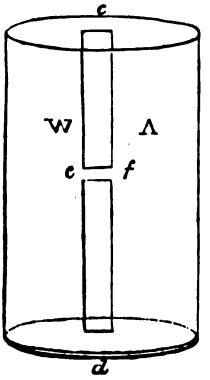
Although the instrument may have suggested inappropriate

names, it is convenient both for experiment and to refer to in explanation of the process of the absorption of fluids by bloodvessels; for, as in the endosmometer we have a cavity filled with one fluid, and separated by an organized membrane from another fluid, so in the bloodvessels we have the blood separated by the organized walls of the vessels from whatever fluid or other substance may be placed in contact with their external surface; and the absorption by the bloodvessels is coars[illegible]id passing into the endosmometer more rapid[illegible]t contains passes out.

The following exp[illegible]ss is borrowed and adapted from that given by [illegible]ower (cxliii. 1835), which appears as sufficient as [illegible]nt of a process so various in its details can be.

Suppose two flu[illegible]t by their surfaces, without any intervening s[illegible]such fluids as will mix together, we may ca[illegible] they will tend to mix the *force of mixture*. [illegible]h fluids capable of mixing, instead of being brought into complete and plain contact with the other, were soaked in a membrane or any animal tissue, and in this state presented to the contact, the mixture would still take place, only now a part of the process of mixing would take place *in the pores* of the membrane. These pores of the membrane may be represented as capillary tubes traversing its thickness; and for illustration we may take the case of a single such pore or tube. Let it then be supposed that two miscible fluids (say alcohol and water, A and W, Fig. 50) are separated by a membranous partition *c d*, of which *e f* represents a single pore; and suppose the two fluids brought at the same instant into contact with the opposite surfaces of the membrane. The forces that will act upon them are the capillary attraction of the pores and their tendency to mix together.

Fig. 50.



The capillary pore *e f* (which may singly represent what all the rest will do) may attract both alcohol and water, as a capillary glass tube would; and it depends on the substance composing the membrane which of the fluids would be most attracted. If the membrane were caoutchouc it would most attract the alcohol; if it were an animal membrane its capillary attraction would be more powerful for the water. Suppose, however, that it were such a membrane as exercised equal capillary attraction for both fluids, they would then both be drawn with equal force, and at the same time, into the pores of the membrane, and they would meet midway in its substance. Thus, in each such capillary tube as *e f*, particles,

like small columns, of alcohol and water would come into contact. The force of capillary attraction remaining equal for both, neither of them could, under the influence of this force, make further progress; for neither could move without displacing the other, and both are held in their places by equal force. But they may mix within the pores in which they are in contact; and thus mixing, particles of each would gradually pass through the membrane to the larger mass of the other. In such a case the interchange would be equal; for there is no law for the mixing of liquids similar to that for the diffusion of gases.

But such a case as is here supposed would very rarely happen; since there are, perhaps, few membranes whose pores have exactly equal capillary attraction for two different fluids. Let us, therefore, next suppose the partition *c d*, to be an animal membrane, which will attract water more than alcohol. At the first contact of the membrane with the two fluids, it is imaginable that both will enter the pores at their opposite ends: but presently the water will displace the alcohol, and will fill the pores; the pores will, for an instant, contain water alone, and the whole surface of the membrane next to the alcohol will present particles of water to its contact. Here, therefore, the water will tend to mix with the alcohol, and provided the tendency to mix, or force of mixture, be as great as the difference between the capillary attractions of the membrane for the two fluids, the water will be carried into the alcohol as fast as it is brought to it, and thus a stream of water will set through the pores towards the alcohol; for as often as the water is taken from the end *f*, of the pore, so often will the capillary attraction of that end of the pore draw on more water from *e*. It is shown by Mr. Power, that, provided the fluids have a tendency to mix, the force with which the one the pores have most attraction for will be carried into the other is equal to the difference of the forces with which the two would be respectively drawn into capillary tubes of the diameter of *e f*, and indefinitely prolonged.

Thus, then, the more rapid current is carried through the membrane with a double force; that of the capillary attraction of the pores, and that of the tendency to mix. The other, *i. e.*, the alcohol, in the case supposed, has no capillary attraction by the membrane in its favor, but passes through the membrane by mixing with the water in its pores and then with the mass of water on the other side. For as we supposed the water to mix with and pass off into the alcohol at *f*, so will particles of the alcohol at that point enter the pore, and, without coming into contact with its walls (whose superior attraction for water keeps it alone in contact with them), will gradually traverse it. Thus may we suppose the pores, filled with particles of alcohol and water, traversing it in both directions; the water passing in a stream or column through each

pore, the alcohol going through, as it were, against the tide, in separate molecules.

Mr. Power has shown that the force with which, on his theory, the endosmotic current would pass through the membrane, would be as great as is manifested in some of the experiments of Dutrochet and others, in which the fluid was raised against a pressure equal to that of 4½ atmospheres, or nearly seventy pounds on the square inch. Th attraction is inversely proportionate to the illary tubes; and must be almost incalculal nmeasurably minute as are the pores of the

It seems bett ation of the process, rather than enter into t f the numerous experiments lately performed atteucci, and others, whose names are subjoi es to the papers which the student may con ossible at present to reduce the facts they record into any general statements; yet they are not more various or inexplicable than might be expected, while we are wholly ignorant of the size and structure of the pores in the several tissues, of the respective degrees of capillary attraction which those of each tissue exercise on each of the several fluids that may be presented to them, of the effects of the interposition of several layers of different tissues, and of an incalculable variety of other conditions of living organs and fluids, which are not imitable in any experiments. It will be sufficient to mention some facts observed in the absorption by bloodvessels, which are explicable by what has been said, or by what experiments on the permeation of membranes have shown.

Much depends on the facility with which the substance to be absorbed can penetrate the membrane or tissue which lies between it and the bloodvessels; for, naturally, the bloodvessels are not bare to absorb. Thus absorption will hardly take place through the epidermis, but is quick when the epidermis is removed, and the same vessels are covered with only the surface of the cutis or granulations. In general, the absorption through membranes is in an inverse proportion to the thickness of their epithelia; so Müller found the urinary bladder of a frog traversed in less than a second; and the absorption of poisons by the stomach or lungs, appears sometimes accomplished in an immeasurably small time.

The substance to be absorbed must, as a general rule, be in the liquid or gaseous state, or, if a solid, must be soluble in the fluids with which it is brought in contact. Hence, the marks of tattooing, and the discoloration produced by nitrate of silver, taken internally, remain. Mercury may be absorbed even in the metallic

[1] Matteucci (cxliv.), Liebig (cxlv.), Jolly (xxxiii. 1848, p. 83), and Vogel (cxlviii.)

state, and in that state may pass into and remain in the blood-vessels, or be deposited from them (Oesterlen, viii. Feb. 1844); and such substances as exceedingly finely-divided charcoal, when taken into the alimentary canal, have been found in the mesenteric veins (Oesterlen, ix. 1847, p. 56); the insoluble materials of ointments may also be rubbed into the bloodvessels; but there are no facts to determine how these various substances effect their passage. Oil, minutely divided, as in an emulsion, will pass slowly into bloodvessels, as it will through a filter moistened with water (Vogel).

The less dense the fluid to be absorbed, the more speedy, as a general rule, is its absorption by the bloodvessels. Hence the rapid absorption of water from the stomach, and of weak saline solutions; but with strong solutions there appears less absorption into, than effusion from, the bloodvessels.

The absorption is the less rapid the fuller and tenser the blood-vessels are, and the tension may be so great as to hinder altogether the entrance of more fluid. Thus, Magendie found that when he injected water into a dog's veins to repletion, poison was absorbed very slowly; but when he diminished the tension of the vessels by bleeding, the poison acted quickly. So, when cupping-glasses are placed over a poisoned wound, they retard the absorption of the poison, not only by diminishing the velocity of the circulation in the part, but by filling all its vessels too full to admit more. On the same ground, absorption is the quicker the more rapid the circulation of the blood is; not because the fluid to be absorbed is more quickly imbibed into the tissues, or mingled with the blood, but because as fast as it enters the blood it is carried away from the part, and the blood being constantly renewed, is constantly as fit as at the first for the reception of the substance to be absorbed.[1]

CHAPTER X.

NUTRITION AND GROWTH.

NUTRITION, or nutritive assimilation, is that modification of the formative process peculiar to living bodies (p. 37), by which tissues and organs already formed maintain their integrity. By the incorporation of fresh nutritive principles into their substance, the loss consequent on the waste and natural decay of the component parti-

[1] [For more extended and recent views on the subject of Endosmose, the reader is referred to Dr. Carpenter's Principles of General and Comparative Physiology, *art.* "*Absorption.*"]

cles of the tissues is repaired; and each elementary particle seems to have the power not only of attracting materials from the blood, but of causing them to assume its structure, and participate in its vital properties. Thus, apparently from similar materials, nerves form nervous substance, muscles muscular substance, and even morbid structures have the assimilating power.

The differences between development, growth, and simple nutrition or maintenance, hav stated (p. 38); under the head of NUTRITION wil red the process by which parts are maintained in l conditions of form, size, and composition, whi ady, by development and growth, attained; and ling, but rather by means of, continual changes in nt particles. It is by this process that an adul , is maintained, through a series of some years, ral outline of features, the same size and form, a he same weight; although, during all this time, the several portions of his body are continually changing: their particles decaying and being removed, and then replaced by the formation of new ones, which, in their turn, also, die and pass away. Neither is it only a general similarity of the whole body which is thus maintained. Every organ and part of the body, as much as the whole, exactly maintains its form and composition, in the issue of the changes continually taking place among its particles.

The change of component particles, in which the nutrition of organs consists, is most evidently shown when, in growth, they maintain their form and other general characters, but increase in size. When, for example, a long bone increases in circumference, and in the thickness of its walls, while, at the same time, its medullary cavity enlarges, it can only be by the addition of materials to its exterior, and a coincident removal of them from the interior of its wall; and so it must be with the growth of even the minutest portions of a tissue. And that a similar change of particles takes place, even while parts retain a perfect uniformity, may be proved, if it can be shown that all the parts of the body are subject to waste and impairment.

In many parts the removal of particles is evident. Thus, as will be shown when speaking of secretion, the elementary structures composing glands are the parts of which the secretions are composed: each gland is constantly casting off its cells or other contents in the secretion which it forms: yet, each gland maintains its size and proper composition, because for every cell cast off a new one is produced. So also the epidermis and all such tissues are maintained. In the muscles, it seems nearly certain that each act of contraction is accompanied with a change in the composition of the contracting tissue. Thence, the development of heat in acting

muscles (p. 154), and thence, the increased discharge of urea, carbonic acid and water—the ordinary products of the decomposition of the animal tissues—which always follows active muscular exercise. Indeed, the researches of Helmholtz almost demonstrate the chemical change that muscles undergo after long-repeated contractions (lxxx. 1845): yet the muscles retain their structure and composition, because the particles thus changed are replaced by new ones like what they were before the change. So, again, the increase of alkaline phosphates discharged with the urine after great mental exertion, seems to prove that the various acts of the nervous system are attended with change in the composition of the nervous tissue; yet the condition of that tissue is maintained. In short, for every tissue there is sufficient evidence of impairment in the discharge of its functions: without such change the production or resistance of physical force is hardly conceivable: and the proof as well as the purpose of the nutritive process appears in the repair or replacement of the changed particles, so that, notwithstanding its losses, each tissue is maintained unchanged.

But besides the impairment and change of composition to which all parts are subject in the discharge of their natural functions, an amount of impairment which will be in direct proportion to their activity, they are all liable to decay and degeneration of their particles, even while their natural actions are not called forth. It may be proved, as Dr. Carpenter first clearly showed (cxxxi. p. 546, Am. Ed.), that every particle of the body is formed for a certain period of existence in the ordinary conditions of active life; at the end of which period, if not previously destroyed by outward force or exercise, it degenerates and is absorbed, or dies and is cast out.

The simplest examples that can be adduced of this are in the hair and teeth; and it may be observed that in the process which will now be described, all the great features of the process of nutrition seem to be represented.[1]

An eyelash which naturally falls, or which can be drawn out without pain, is one that has lived its natural time, and has died, and been separated from the living parts. In its bulb such an one will be found different from those that are still living in any period of their age. In the early period of the growth of a dark eyelash, the medullary substance appears like an interior cylinder of darker granular substance, continued down to the deepest part,

[1] These and other instances are related in more detail in Mr. Paget's Lectures, at the College of Surgeons, on Nutrition, Hypertrophy, and Atrophy (lxxi. vol. xxxix.), of which the principal part of this chapter is an abstract. In connection with this subject, Mr. Paget's subsequent Lectures on Repair and Inflammation, published in the Medical Gazette, 1849 and 1850, may be consulted with advantage.

Fig. 51.

Intended to represent the changes undergone by a hair towards the close of its period of existence. At A, its activity of growth is diminishing, as shown by the small quantity of pigment contained in the cells of the pulp, and by the interrupted line of dark medullary substance. At B, provision is being made for the formation of a new hair, by the growth of a new pulp connected with the pulp or capsule of the old hair. C. A hair at the end of its period of life, deprived of its sheath and of the mass of cells composing the pulp of a living hair.

where the hair enlarges to form the bulb. This enlargement, which is of nearly cap-like form, appears to depend on the accumulation of nucleated cells, whose nuclei, according to their position, are, either by narrowing and elongation, to form the fibrous substance of the outer part of the growing and further proceeding hair, or are to be transformed into the granular matter of its medullary portion. At the time of early and most active growth, all the cells and nuclei contain abundant pigment-matter, and the whole bulb looks nearly black. The sources of the material out of which the cells form themselves are, at least, two; the inner surface of the sheath, or capsule, which dips into the skin, enveloping the hair, and the surface of a vascular pulp, which fits in a conical cavity in the bottom of the hair-bulb.

Such is the state of parts so long as the growing hair is all dark. But as the hair approaches the end of its existence, instead of the almost sudden enlargement at its bulb, it only swells a little, and then tapers nearly to a point; the conical cavity in its base is contracted; and the cells produced on the inner surface of the capsule contain no pigment. Still, for some time it continues thus to live and grow; and the vigor of the pulp lasts rather longer than that of the sheath or capsule, for it continues to produce pigment matter for the medullary substance of the hair after the cortical substance has become white. Thus, the column of dark medullary substance appears paler and more slender, and perhaps interrupted, down to the point of the conical pulp, which, though smaller, is still distinct, because of the pigment-cells covering its surface.

At length the pulp can be no longer discerned, and uncolored

cells alone are produced, and maintain the latest growth of the hair. With these it appears to grow yet some further distance, for traces of the elongation of their nuclei into fibres appear in lines running from the inner surface of the capsule inwards and along the surface of the hair; and the column of dark medullary substance ceases at some distance above the lower end of the contracted hair-bulb. The end of all is the complete closure of the conical cavity in which the hair-pulp was lodged, the cessation of the production of new cells from the inner surface of the capsule, and the detachment of the hair which, as a dead part, is separated and falls.

Such is the life of a hair, and such its death; which death is spontaneous, independent of exercise, or of any mechanical external force—the natural termination of a certain period of life. Yet, before the hair dies, provision is made for its successor; for when its growth is failing, there appears just below its base a dark spot, the germ or young pulp of the new hair covered with cells containing pigment, and often connected by a series of pigment-cells with the old pulp or capsule (Fig. 51, B).

Probably there is an intimate analogy between the process of successive life and death, and life communicated to a successor, which is here shown, and that which constitutes the ordinary nutrition of a part. It may be objected that the death and casting out of the hair cannot be imitated in internal parts; therefore, for an example in which the assumed absorption of the wornout or degenerate internal particles is imitated in larger organs at the end of their appointed period of life, the instance of the deciduous or milk-teeth may be adduced.

Each milk-tooth is developed from its germ, and, in the course of its own development, separates a portion of itself to be the germ of its successor; and each, having reached its perfection, retains for a time its perfect state, and still lives, though it does not grow. But at length, as the new tooth comes, the deciduous tooth dies; or rather, its crown dies, and is cast out like the dead hair, while its fang with its bony sheathing, and vascular and nervous pulp, degenerates and is absorbed (Fig. 52). The degeneration is accompanied by some unknown spontaneous decomposition of the fang, for it could not be absorbed unless it was first so changed as to be soluble. And it is degeneration,

Fig. 52.

Section of portion of the upper jaw of a child, showing a new tooth in process of formation, the fang of the corresponding deciduous tooth being absorbed.

not death, wh[illegible]h precedes its removal; for when a tooth-fang dies, as that of the [illegible]econd tooth does in old age, then it is not absorbed, but is cast ou[illegible]entire, as a dead part.

Such, or g[illegible]erally such, it seems almost certain, is the process of maintenanc[illegible] by nutrition; the hair and teeth may be fairly taken as types of what occurs in other parts, for they are parts of complex organic structure and composition, and the teeth-pulps, which are absorb[illegible]angs, are very vascular and sensitive.

Nor are thev[illegible]might be adduced. The like development[illegible]the perfect state, death, and discharge a[illegible]of cuticles and gland-cells; and in the [illegible]there is evidence of decomposition of t[illegible]the different influence which acetic acid and[illegible]n and on the younger cells. Seeing then tha[illegible]on, as thus displayed both in active organs and in elementary cells, appears in these respects similar, the general conclusion may be that, in nutrition, the ordinary course of each complete elementary organ in the body, after the attainment of its perfect state by development and growth, is, to remain in that state for a time; then, independently of the death or decay of the whole body, and, in some measure, independently of its own exercise, or exposure to external violence, to die or to degenerate; and then, being cast out or absorbed, to make way for its successor.

It appears, moreover, that the length of life which each part is to enjoy is fixed and determinate, though in some degree subject to accidents and to the expenditure of life in exercise. It is not likely that all parts are made to last a certain and equal time, and then all need to be changed. The bones, for instance, when once completely formed, must last longer than the muscles and other softer tissues. But, when we see that the life of certain parts is of determined length, whether they be used or not, we may assume, from analogy, the same of nearly all.

Now, the deciduous human teeth have an appointed average duration of life. So have the deciduous teeth of all other animals; and in all the numerous instances of moulting, shedding of antlers, of desquamation, change of plumage in birds, and of hair in Mammalia, the only explanation is that these organs have their severally appointed times of living, at the end of which they degenerate, die, are cast away, and in due time are replaced by others, which, in their turn, are to be developed to perfection, to live their life in the mature state, and, in their turn, to be cast off. So also, in some elementary structures, we may discern the same laws of determinate period of life, death, or degeneration, and replacement. They are evident in the history of the blood-corpuscles, both in the

superseding of the first set of them by the second at a definite period in the life of the embryo, and in the replacement of those that degenerate by others new-formed from lymph-corpuscles (see pp. 62–65). And if we could suppose the blood-corpuscles grouped together in a tissue instead of floating, we might have in the changes they present an image of the nutrition of the elements of the tissues.

The *duration of life in each particle* is, however, liable to be modified; especially by the exercise of the function of the part. The less a part is exercised the longer do its component particles appear to live; the more active its functions are, the less prolonged is the existence of its individual particles. So in the case of single cells; if the general development of the tadpole be retarded by keeping it in a cold dark place, and if hereby the function of the blood-corpuscles be slowly and imperfectly discharged, they will maintain their embryonic state for even several weeks later than usual, the development of the second set of corpuscles will be proportionally postponed, and the individual life of the corpuscles of the first set will be, by the same time, prolonged.

Such being the modes in which the necessity for the process of nutritive maintenance is created, such the sources of impairment and waste of the tissues, the next consideration may be, the manner in which the perfect state of a part is maintained by the insertion of new particles in the place of those that are absorbed or cast off.

The *process by which a new particle is formed* in the place of the old one is probably always a process of development; that is, the cell or fibre, or other element of tissue, passes, in its formation, through the same stages of development as those elements of the same tissue did which were first formed in the embryo. This is probable from the analogy of the hair, the teeth, the epidermis, and all the tissues that can be observed: in all, the process of repair or replacement is effected through development of the new parts. The existence of nuclei or cytoblasts in nearly all parts that are the seats of active nutrition makes the same probable. For these nuclei, such as are seen so abundant in strong, active muscles, are not remnants of the embryonic tissue, but germs or organs of power for new formation, and their abundance often appears directly proportionate to the activity of growth. Thus, they are always abundant in the fœtal tissues, and those of the young animal; and they are peculiarly numerous in the muscles and the brain, and their disappearance from a part in which they usually exist is a sure accompaniment and sign of degeneration.

A difference may be drawn between what may be called *nutritive reproduction* and *nutritive repetition*. The former is shown in the case of the human teeth. As the deciduous tooth is being developed, a part of its productive capsule is detached, and serves as a

germ for the formation of the second tooth; in which second tooth, therefore, the first may be said to be reproduced, in the same sense as that in which we speak of the organs by which new individuals are formed, as the reproductive organs. But in the shark's jaws, and others, in which we see row after row of teeth succeeding each other, the row behind is not formed of germs derived from the row before; the front row is simply repeated in the second one, the second in the third, and s… nticle, the deepest layer of epidermis-cells derives nc… e layer above them; their development is not like a… f the cells that have gone on towards the surface be… only a repetition. So, as already pointed out, the l… ined by constant repetition of the process of the dev… w corpuscles, new fibrine, and other materials from… chyle; the new corpuscles being not derived thro… ated from old ones. It is not improbable that m… ice in the degrees of repair of which the several tissues are capable after injuries or diseases, may be connected with these differences in their ordinary mode of nutrition.

In order that the process of nutrition may be perfectly accomplished certain conditions are necessary. Of these, the most important are: 1. A right state and composition of the blood, from which the materials for nutrition are derived. 2. A regular and not far distant supply of such blood. 3. A certain influence of the nervous system. 4. A natural state of the part to be nourished.

1. This *right condition* of the blood does not necessarily imply its accordance with any known standard of composition common to all kinds of healthy blood, but rather the existence of a certain adaptation between the blood and the tissues, and even the several portions of each tissue. Such an adaptation, peculiar to each individual, is determined in its first formation, and is maintained in the concurrent development and increase of both blood and tissues; and upon its maintenance in adult life appears to depend the continuance of a healthy process of nutrition, or at least the preservation of that exact sameness of the whole body and its parts which constitutes the perfection of nutrition. Some notice of the maintenance of this sameness in the blood has been given already (p. 67), in speaking of the power of assimilation which the blood exercises, a power exactly comparable with this of maintenance by nutrition in the tissues. And evidence of the adaptation between the blood and the tissues, and of the exceeding fineness of the adjustment by which it is maintained, is afforded by the phenomena of symmetrical diseases, in which, in consequence of some morbid condition of the blood, a change of structure effects in an exactly similar way the precisely corresponding parts on the two sides of the body, and

no other parts of even the same tissue.[1] These phenomena can only be explained on the assumption, 1st, of the complete and peculiar identity in composition in the corresponding parts of opposite sides of the body; and, 2dly, of so precise and complete an adaptation between the blood and the several parts of each tissue, that a morbid material being present in the blood may destroy its fitness for the nutrition of one or two portions of any tissue, such as the skin or the bones, without affecting its fitness for the maintenance of other portions of the same tissue. But if the blood can be fit for the maintenance of one part, and unfit for the maintenance of another part, of what appears by every other test that we can apply the very same tissue, how precise must that adaptation of the blood to the whole body be, by which in health it is always capable of maintaining not only the whole number of different organs and tissues, but all the different parts of every one of them.

2. The necessity of an *adequate supply of appropriate blood in or near the part to be nourished*, in order that its nutrition may be perfect, is shown in the frequent examples of atrophy of parts to which too little blood is sent, of mortification or arrested nutrition, when the supply of blood is entirely cut off, and of defective nutrition when the blood is stagnant in a part. That the nutrition of a part may be perfect, it is also necessary that the blood should be brought sufficiently near to it for the elements of the tissue to imbibe, through the walls of the bloodvessels, the nutritive materials which they require. The bloodvessels themselves take no share in the process of nutrition, except as carriers of the nutritive matter. Therefore, provided they come so near that this nutritive matter may pass by imbibition into the part to be nourished, it is comparatively immaterial whether they ramify within the substance of the tissue, or are distributed only on its surface or border.

The bloodvessels serve alike for the nutrition of the vascular and the non-vascular parts, the difference between which, in regard to nutrition, is less than it may seem (see p. 106). For the vascular, the nutritive fluid is carried in streams into the interior; for the non-vascular, it flows on the surface; but in both alike, the parts themselves imbibe the fluid; and though the passage through the walls of the bloodvessels may effect some change in the materials, yet all the process of formation is, in both alike, outside the vessels. Thus, in muscular tissue, the fibrils in the very centre of the fibre nourish themselves; yet these are distant from all bloodvessels, and can only by imbibition receive their nutriment. So, in bones, the spaces between the bloodvessels are wider than in

[1] For examples and illustrations of symmetrical diseases, see two papers on the subject, published by Dr. William Budd and Mr. Paget, in the twenty-fifth volume of the Medico-Chirurgical Transactions.

muscle; yet the parts in the meshes nourish themselves, imbibing materials from the nearest source. The non-vascular epidermis, though no vessels pass into its substance, yet imbibes nutritive matter from the vessels of the immediately subjacent cutis, and maintains itself, and grows. The instances of the cornea and vitreous humor are stronger, yet similar; and, sometimes, even the same tissue is in one case vascular, in the other not—as the osseous tissue, which, when [illegible] thick layers, has bloodvessels running into it; bu[illegible] layers, as in the lachrymal and turbinated bones, [illegible] bones subsist on the blood flowing into the minute [illegible]eous membrane, from which the epithelium derive[illegible] one side, the bone on the other, and the ti[illegible]e itself, on every side: a striking instance [illegible]me materials, many tissues maintain themselves, [illegible]ts peculiar assimilative and self-formative power.

3. The third conditi[illegible] sential to healthy nutrition, is *a certain influence of the nervous system.*

It has been held that the nervous system cannot be essential to a healthy course of nutrition, because in plants and the early embryo, and in the lowest animals in which no nervous system is developed, nutrition goes on without it. But this is no proof that in animals which have a nervous system nutrition may be independent of it; rather, it may be assumed that in ascending development, as one system after another is added or increased, so the highest (and highest of all the nervous system) will always be inserted and blended in a more and more intimate relation with all the rest: according to the general law, that the interdependence of parts augments with their development.

The reasonableness of this assumption is proved by many facts showing the influence of the nervous system on nutrition, and by the most striking of these facts being observed in the higher animals, and especially in man. The influence of the mind in the production, aggravation, and cure of organic diseases is matter of daily observation, and a sufficient proof of influence exercised on nutrition through the nervous system.

Independently of mental influence, injuries, either to portions of the nervous centres, or to individual nerves, are frequently followed by defective nutrition of the parts supplied by the injured nerves, or deriving their nervous influence from the damaged portions of the nervous centres. Thus, lesions of the spinal cord are sometimes followed by mortification of portions of the paralyzed parts; and this may take place very quickly, as in a case by Sir B. C. Brodie (clvi. p. 309), in which the ankle sloughed within twenty-four hours after an injury of the spine. After such lesions, also, the repair of injuries in the paralyzed parts may take place less

completely than in others; so, Mr. Travers mentions a case in which paraplegia was produced by fracture of the lumbar vertebræ, and, in the same accident, the humerus and tibia were fractured. The former in due time united; the latter did not (xcviii. p. 436). The same fact was illustrated by some experiments of Dr. Baly, in which having, in salamanders, cut off the end of the tail, and then thrust a thin wire some distance up the spinal canal, so as to destroy the cord, he found that the end of the tail was reproduced more slowly than in other salamanders in whom the spinal cord was left uninjured above the point at which the tail was amputated (xxxii. p. 480, Am. Ed.). Illustrations of the same kind are furnished by the several cases in which division or destruction of the trunk of the trigeminal nerve has been followed by incomplete and morbid nutrition of the corresponding side of the face; ulceration of the cornea being not unfrequently one of the consequences of such imperfect nutrition.[1] Part of the wasting and slow degeneration of tissue in paralyzed limbs is probably referable, also, to the withdrawal of nervous influence from them; though, perhaps, more is due to the want of use of the tissues.

Undue irritation of the trunks of nerves, as well as their division or destruction, is sometimes followed by defective or morbid nutrition. To this may be referred the cases in which ulceration of the parts supplied by the irritated nerves occurs frequently, and continues so long as the irritation lasts (see lxxi. vol. xxxix. p. 1022). Further evidence of the influence of the nervous system upon nutrition is furnished by those cases in which, from mental anguish, or in severe neuralgic headaches, the hair becomes gray very quickly, or even in a few hours. And to all these may, perhaps, be added the facts that where any particular nerves have been deficient, the parts corresponding to them have likewise always been absent; and where any organ is wanting, there is generally a corresponding absence of the nerves. Tiedemann (xcix. vol. i. p. 76) relates three cases of absence of the olfactory nerves coincident with an imperforate state of the cribriform plate of the ethmoid bone and cleft palate. Absence of the eyes is also attended with absence of their nerves.

So many and various facts leave little doubt that the nervous system exercises an influence over nutrition as over other organic processes; and they cannot be explained by supposing that the changes in the nutritive processes are only due to variations in the size of the bloodvessels supplying the affected parts.

The question remains, through what class of nerves is the influ-

[1] See the particulars of such a case by Mr. Stanley (lxxi. vol. i. p. 531), and the cases by Mr. Dixon, in the twenty-eighth volume of the Medico-Chirurgical Transactions; also the results of experiments on frogs, by Stannius (lxxx. 1847, p. 458).

ence exerted? When defective nutrition occurs in parts rendered inactive by injury of the motor nerves alone, as in the muscles and other tissues of a paralyzed face or limb, it may appear as if the atrophy were the direct consequence of the loss of power in the motor nerves; but it is more probable that the atrophy is the consequence of the want of exercise of the parts; for if the muscles be exercised by artificial irritation of their nerves, their nutrition will be less defective (J. Reid). The defect of the nutritive process which ensues in the parts, in consequence of destruction of the trigem[inal] must be referred more directly to the loss of influence [through] sensitive or sympathetic nerves; for the motor [nerves of the] eye, as well as the olfactory and optic, have [the] defective nutrition which follows injury of the t[rigeminal], and one or all of them may be destroyed without [any] appearance of the nutrition of the parts they severally s[upply].

The direct influence [exercised by the] sensitive and sympathetic nerves over the process of nutrition, thus proved in the case of the trigeminal nerve, is probably only an example of what is generally true. A similar influence is shown in the cases in which sloughing of parts from injury or disease of the spinal cord has ensued earlier and more extensively when sensation, than when motion alone was lost;[1] and in other cases in which the wasting of a paralyzed limb is, after a certain time, more marked when both sensation and motion are impaired than when the power of motion alone is interfered with.

It is not at present possible to say whether the influence on nutrition is exercised through the sensitive or through the sympathetic nerves which, in the parts on which the observation has been made, are generally combined in the same sheath. The truth perhaps is, that it may be exerted through either or both of these nerves. The defect of nutrition which ensues after lesion of the spinal cord alone, the sympathetic nerves being uninjured, and the general atrophy which sometimes occurs in consequence of diseases of the brain, seem to prove the influence of the cerebro-spinal system; while the observation of Magendie and Longet, that destructive disease of the eye ensues more quickly after division of the trigeminal nerve in front of the Casserian ganglion, where it is joined by the sympathetic fibres which pass with it to the eye, than when the division is made between the ganglion and the brain, seems to prove the influence of the sympathetic more than of the sensitive nerves.

4. The fourth condition necessary to healthy nutrition is a healthy state of the part to be nourished. This seems proved by

[1] See a case of this kind, recorded by Mr. Curling, in the twentieth volume of the Medico-Chirurgical Transactions.

the very nature of the process, which consists in the formation of new parts like those already existing; for unless the latter are healthy the former cannot be so. Whatever be the condition of a part, it is apt to be perpetuated by assimilating exactly to itself, and endowing with all its peculiarities the new particles which it forms to replace those that degenerate. So long as a part is healthy, and the other conditions of healthy nutrition exist, it maintains its healthy condition. But, according to the same law, if the structure of a part be diseased, or in any way altered from its natural condition, the alteration is maintained; the altered, like the healthy, structure is perpetuated. The same exactness of the assimilation of the new parts to the old, which is seen in the nutrition of the healthy tissues, may be observed, also, in those that are formed in disease. By it, the exact form and relative size of a cicatrix are preserved from year to year; by it, the thickening and induration to which inflammation gives rise are kept up, and the various morbid states of the blood in struma, syphilis, and other chronic diseases are maintained, notwithstanding all diversities of diet. By this precision of the assimilative process may be explained the law that certain diseases occur only once in the same person, and that certain others are apt to recur frequently; because, in both cases alike, the alteration produced by the first attack of the disease is maintained by the exact likeness which the new parts bear to the old ones.

The period, however, during which an alteration of structure may be exactly maintained by nutrition, is not unlimited; for in nearly all altered parts there appears to exist a tendency to recover the perfect state; and in many cases, this state is, in time, attained. To this we may attribute the possibility of revaccination after the lapse of some years; the occasional recurrence of smallpox, scarlet fever, and the like diseases, in the same person; the wearing out of scars, and the complete restoration of tissues that have been altered by injury or disease.

Such are some of the more important conditions which appear to be essential to healthy nutrition. Absence or defect of any one of them is liable to be followed by disarrangement of the process; and the various diseases resulting from defective nutrition, appear to be due to the failure of these conditions, more often than to imperfection of the process itself.

GROWTH.

Growth, as has been already observed (page 38,) consists in the increase of a part in bulk and weight, by the addition to its substance of particles similar to its own, but more than sufficient to replace those which it loses by the waste or natural decay of its

tissue. The structure and composition of the part remains the same, but the increase of healthy tissue which it receives, is attended with the capability of discharging a larger amount of its ordinary function.

While development is in progress, growth and it frequently go on together in the same part, as in the formation of the various organs and tissues of the embryo, in which parts, while they grow larger, are also grau oped until they attain their perfect state. But, a continues after development is completed, and, i ntinues even after the full stature of the body ter nearly every portion of it has gained its perfe e and composition.

Thus the heart, i ording to Dr. Clendinning's examinations (lxxi. ceases to grow only with the cessation of life. ditions, this continuance, or a renewal, of growt in nearly every part of the body. When parts full size, which in the ordinary process of growth they reach, and are then kept in a moderate exercise of their functions, they commonly (as already stated) retain almost exactly the same dimensions through the adult period of life. But when, from any cause, a part already full-grown in proportion to the rest of the body, is called upon to discharge an unusual amount of its ordinary function, the demand is met by a corresponding increase or growth of the part. Illustrations of this are afforded by the increased thickening of cuticle at parts where it is subjected to an unusual degree of occasional pressure or friction, as in the palms of the hands of persons employed in rough manual labor; by the enlargement and increased hardness of muscles that are largely exercised; and by many other facts of a like kind. The increased power of nutrition put forth in such growth, is greater than might be supposed; for the immediate effect of increased exercise of a part, must be a greater using of its tissue, and might be expected to entail a permanent thinning or diminution of the substance of the part. But the energy with which fresh particles are formed, is sufficient not only to replace completely those that are worn away, but to cause an increase in the substance of the part—the amount of this increase being proportioned to the more than usual degree in which its functions are exercised.

The growth of a part from undue exercise of its functions is always, in itself, a healthy process; and the increased size which results from it must be distinguished from the various kinds of enlargement to which the same part may be subject from disease. In the former case, the enlargement is due to an increased quantity of healthy tissue, providing more than the previous power to meet a particular emergency; the other may be the result of a deposit of

morbid material within the natural structure of the part, diminishing, instead of augmenting, its fitness for its office. Such a healthy process of growth in a part attended with increased power and activity of its function may, however, occur as the consequence of disease in some other part; in which case it is commonly called *Hypertrophy*, *i. e.*, excess of nutrition. The most familiar examples of this are in the increased thickness and robustness of the muscular walls of the cavities of the heart in cases of continued obstruction to the circulation; and in the increased development of the muscular coat of the urinary bladder when, from any cause, the free discharge of urine from it is interfered with. In both these cases, though the origin of the growth is the consequence of disease, yet the growth itself is natural, and its end is the benefit of the economy; it is only common growth renewed or exercised in a part which had attained its size in due proportion to the rest of the body.

It may be further mentioned, in relation to the physiology of this subject, that, when the increase of function, which is requisite in the cases from which hypertrophy results, cannot be efficiently discharged by mere increase of the ordinary tissue of the part, the development of a new and higher kind of tissue is frequently combined with this growth. An example of this is furnished by the uterus, in the walls of which, when it becomes enlarged by pregnancy, or by the growth of fibrous tumors, organic muscular fibres, not found in its quiescent state, are developed, and provide for the expulsion of the fœtus or the foreign body. Other examples of the same are furnished by cases in which, from obstruction to the discharge of their contents, and a consequently increased necessity for propulsive power, the coats of reservoirs and of ducts become the seat of the development of organic muscular fibres, which either did not exist in them before, or were in very small quantity. Such development of muscular fibres has been seen in the thickened coats of the gall-bladder and in those of the ureter (Tourtual, lxxx. 1842).

Respecting the mode and conditions of the process of growth, it needs only to be said, that its mode seems to differ only in degree from that of common maintenance of a part; more particles are removed from, and many more added to, a growing tissue, than one which only maintains itself. But so far as can be ascertained, the mode of removal, the disposition of the removed parts, and the insertion of the new particles, are as in simple maintenance. The conditions also of growth are the same as those of common nutrition, and are equally or more necessary to its occurrence. When they are very favorable or in excess, growth may occur in the place of common nutrition. Thus hair may grow profusely in the neighborhood of old ulcers, in consequence, apparently, of the excessive

supply of blood to the hair-bulbs and pulps; bones may increase in length when disease brings much blood to them; cocks' spurs transplanted from their legs into their combs grow to an unnatural length; and, in the case of double organs, such as the kidneys, when one is destroyed, the other grows to a large size, apparently in consequence of the excess of urea which for a time exists in the blood, and which supplies one of the materials from which the contents of the kidne[illegible]l.

XI.

SECRETION is the process by which materials are separated from the blood, and from the organs in which they are formed, for the purpose either of serving some ulterior office in the economy, or of being discharged from the body as excrement. In the former case, both the separated materials and the processes for their separation are termed *secretions;* in the latter, they are named *excretions.*

Most of the secretions consist of substances which, probably, do not pre-exist in the same form in the blood, but require special organs and a process of elaboration for their formation, *e. g.*, the liver for the formation of bile, the mammary gland for the formation of milk. The excretions, on the other hand, commonly or chiefly consist of substances which, as urea, carbonic acid, and probably uric acid, exist ready formed in the blood, and are merely abstracted therefrom. If from any cause, such as extensive disease or extirpation of an excretory organ, the separation of an excretion is prevented, and an accumulation of it in the blood ensues, it frequently escapes through other organs, and may be detected in various fluids of the body. But this is never the case with secretions; at least with those that are most elaborated; for, after the removal of the special organs by which any of them is elaborated, it is no longer formed. Cases sometimes occur in which the secretion continues to be formed by the natural organ, but, not being able to escape towards the exterior, on account of some obstruction, is reabsorbed into the blood, and afterwards discharged from it by exudation in other ways; but these are not instances of true vicarious secretion, and must not be thus regarded.

These circumstances, and their final destination are, however, the only particulars in which secretions and excretions can be distinguished; for in general the structure of the parts engaged in eliminating excretions, *e. g.*, the kidneys, is as complex as that of the

parts concerned in the formation of secretions. And since the differences of the two processes of separation, corresponding with those in the several purposes and destination of the fluids, are not yet ascertained, it will be sufficient to speak in general terms of the process of separation or secretion.

Every secreting apparatus possesses, as essential parts of its structure, a simple and apparently textureless membrane, named the *primary* or *basement membrane;* certain *cells;* and *bloodvessels.* These three structural elements are arranged together in various ways; but all the varieties may be classed under one or other of two principal divisions, namely, *membranes* and *glands.*

SECRETING MEMBRANES.

The principal secreting membranes are the serous and synovial membranes, the mucous membranes, and the skin.[1]

The *serous membranes* are formed of fibro-cellular tissue interwoven so as to constitute a membrane, the free surface of which is covered with a single layer of flattened cells forming, in most instances, a simple *tessellated epithelium.* Between the epithelium and the subjacent layer of fibro-cellular tissue is situated the primary or basement-membrane (Bowman, lxxiii. art. *Mucous Membrane.* Goodsir, ii. p. 41).

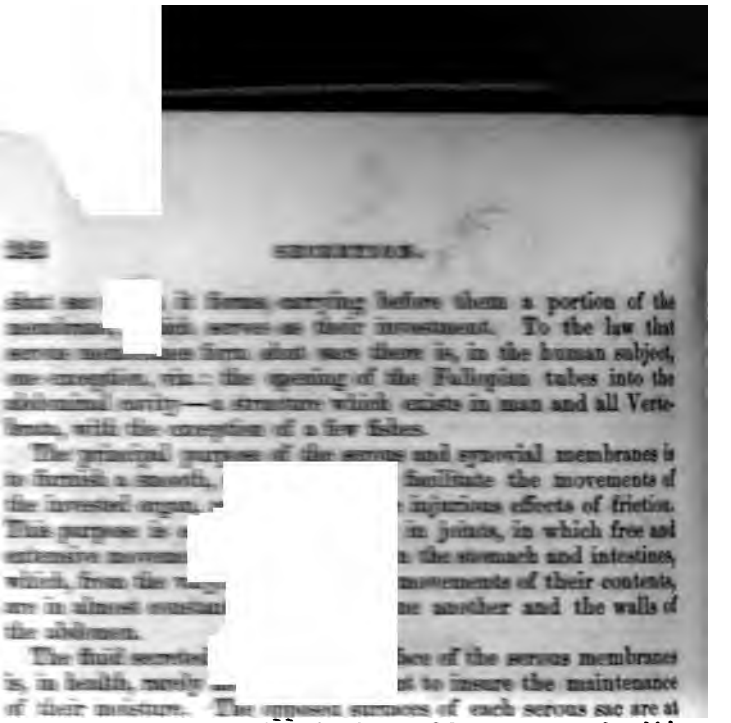
In relation to the process of secretion, the layer of fibro-cellular tissue serves as a groundwork for the ramification of bloodvessels, lymphatics, and nerves.[2] But it is absent in some instances, as in the arachnoid covering the dura mater, and in the interior of the ventricles of the brain. The primary membrane and epithelium are always present, and are concerned in the formation of the fluid by which the free surface of the membrane is moistened.

The serous membranes are of two principal kinds: 1st. Those which line visceral cavities, *e. g.*, the peritoneum, pericardium, pleuræ, arachnoid, and tunicæ vaginales. 2d. The synovial membranes lining the joints, and the sheaths of tendons and ligaments, with which also are usually included the synovial bursæ, or *bursæ mucosæ*, whether these be subcutaneous, or situated beneath tendons that glide over bones.

The serous membranes form closed sacs, and exist wherever the free surfaces of viscera come into contact with each other, or lie in cavities unattached to surrounding parts. The viscera which are invested by a serous membrane, are, as it were, pressed into the

[1] The skin will be described in chapter xiii.

[2] For an account of the nerves of serous membranes, see Purkinje (lxxx. 1845); Bourgery (xix. Sept. 1845); Pappenheim (viii. Oct. 1845); and Rainey (xli. vol. xxix.).



every point in contact with each other, and leave no space in which fluid can collect. After death, a larger quantity of fluid is usually found in such serous sacs: but this, if not the product of manifest disease, is probably such as has transuded after death, or in the last hours of life. An excess of such fluid in any of the serous sacs, constitutes dropsy of the sac.

The fluid naturally secreted by the serous membranes appears to be identical, in general and chemical characters, with the serum of the blood, or with very dilute liquor sanguinis. It is of pale yellow or straw-color, slightly viscid, alkaline, and, because of the presence of albumen, coagulable by heat. The presence of a minute quantity of fibrine, at least in the dropsical fluids effused into the serous cavities, is shown by their partial coagulation into a jelly-like mass on the addition of fibrine or other animal substances, or when mixed with some other serous fluid (see p. 23, *note*). This similarity of the serous fluid to the liquid part of blood, and to the fluid with which most animal tissues are moistened, renders it probable that it is in great measure separated by simple transudation through the walls of the bloodvessels. The probability is increased by the fact that in jaundice the fluid in the serous sacs is, equally with the serum of the blood, colored with the bile. But there is reason for supposing that the fluid of the cerebral ventricles and of the arachnoid sac are exceptions to this rule: for they differ from the fluids of the other serous sacs not only in being pellucid, colorless, and of much less specific gravity, but in that they seldom receive the tinge of bile in the blood, and are not colored by madder, or other similar substances introduced abundantly into the blood.

It is also probable that the formation of synovial fluid is a pro-

ess of more genuine and elaborated secretion, by means of the epithelial cells on the surface of the membrane, and especially of those which are accumulated on the edges and processes of the synovial fringes (Goodsir, ii., Rainey, cxxiii. 1847); for, in its peculiar density, viscidity, and abundance of albumen, synovia differs alike from the serum of blood, and from the fluid of any of the serous cavities.

The *mucous membranes* line all those passages by which internal parts communicate with the exterior, and by which, either matters are eliminated from the body, or foreign substances taken into it. They are soft and velvety, and extremely vascular. Their basis or proper texture, seems to belong to the albuminous structures. Their external surfaces are attached to various other tissues; in the tongue, for example, to muscle; on cartilaginous parts, to perichondrium; in the cells of the ethmoid bone, in the frontal and sphenoid sinuses, as well as in the tympanum, to periosteum; in the intestinal canal it is connected with a firm sub-mucous membrane, which, on its exterior, gives attachment to the fibres of the muscular coat. The internal, or free surface of the mucous membranes, is at every part invested with one or more layers of epithelial cells, which are separated from the vascular tissue by the layer of basement-membrane.

The mucous membranes are described as lining certain principal tracts. 1. The *digestive tract* commences in the cavity of the mouth, from which prolongations pass into the ducts of the salivary glands. From the mouth it passes through the fauces, pharynx, and œsophagus, to the stomach, and is thence continued along the whole tract of the intestinal canal to the termination of the rectum, being in its course arranged in the various folds and depressions already described (chapter viii.), and prolonged into the ducts of the pancreas and liver, and into the gall-bladder. 2. The *respiratory tract* includes the mucous membrane lining the cavity of the nose, and the various sinuses communicating with it, the lachrymal canal and sac, the conjunctiva of the eye and eyelids, and the prolongation which passes along the Eustachian tube, and lines the tympanum and the inner surface of the membrana tympani. Crossing the pharynx, and lining that part of it which is above the soft palate, the respiratory tract leads into the glottis, whence it is continued, through the larynx and trachea, to the bronchi and their divisions, which it lines as far as the branches, of from 1-50th to 1-30th of an inch in diameter (Rainey, xli. vol. xxviii.). 3. The *genito-urinary* tract, which lines the whole of the urinary passages, from their external orifice to the termination of the tubuli uriniferi of the kidneys, extends into and through the organs of generation in both sexes, into the ducts of the glands

connected with them, and in the female becomes continuous with the serous membrane of the abdomen, at the fimbriæ of the Fallopian tubes.

Along each of the above tracts, and in different portions of each of them, the mucous membrane presents certain structural peculiarities adapted to the functions which each part has to discharge; yet, in some essential characters, mucous membrane is the same, from whatever part it is ob[illegible] all the principal and larger parts of the several tract[illegible] an external layer of epithelium, situated upon the [illegible]*brane*, and beneath this, a stratum of vascular tissu[illegible] thickness, which in different cases presents either ou[illegible]e form of papillæ and villi, or depressions or involu[illegible]rm of glands. But, in the prolongations of the tra[illegible]y pass into gland-ducts and their finest branches, t[illegible]s are reduced to the epithelium, the primary or b[illegible]ane, and the capillary bloodvessels spread over the outer surface of the latter in a single layer.

The primary or basement membrane, is a thin transparent layer, simple, homogeneous, and with no discernible structure, which, on the larger mucous membranes that have a layer of vascular fibrocellular tissue, may appear to be only the blastema or formative substance, out of which successive layers of epithelium-cells are formed. But in the minuter divisions of the mucous membranes, and in the ducts of glands, it is the layer, continuous and correspondent with this basement-membrane that forms the proper walls of the tubes. The cells, also, which, lining the larger and coarser mucous membranes, constitute their epithelium, are continuous with, and often similar to those which, lining the gland-ducts are called *gland-cells*, rather than epithelium. Indeed, no certain distinction can be drawn between the epithelium-cells of mucous membranes, and gland-cells. In reference to their position as covering surfaces, they might all be called epithelium-cells, whether they lie on open mucous membranes, or in gland-ducts; and in reference to the process of secretion, they might all be called gland-cells, or at least secreting cells, since they probably all fulfil a secretory office, by separating certain definite materials from the blood, and from the part on which they are seated. It is only an artificial distinction which makes them epithelial-cells in one place, and gland-cells in another.

It thus appears that the tissues essential to the production of a secretion are, in their simplest form, a simple membrane, having on one surface bloodvessels, and on the other a layer of cells which may be called either epithelium-cells, or gland-cells. The first two elements are so similar in all glands and mucous membranes, that it seems nearly certain that the cells are the principal agents in the

process of secretion, a view which is confirmed by many other facts. It will, therefore, be explanatory of the whole process of secretion, if somewhat be said now of the epithelia, or the secreting cells, of the mucous membrane.

The *epithelia* present themselves under three different forms; the characters of each of which are different enough in well-marked examples, but when, as frequently happens, a continuous mucous surface possesses at different parts two or more different epithelia, there is a very gradual transition from one to the other.

The first and most common variety, as described by Henle (xxxvii. p. 220), is the *tessellated* or *pavement epithelium*, which is composed of flat, oval, roundish, or polygonal nucleated cells, of various size, arranged in one, or in many superposed layers (Fig. 53). This form of epithelium is spread over the mouth, pharynx, and œsophagus, the conjunctiva covering the eye, the vagina, and

Fig. 53.

Scales of tessellated epithelium: B, scales taken from the inner surface of the cheek; the margin of one is folded, a frequent appearance of these scales, showing their thinness and flexibility; C, the more deeply seated or recently formed scales or cellules from the human conjunctiva; A, section of the epithelium of the conjunctiva, with some scales loosened. After Henle.

entrance of the female urethra; a similar epithelium lines most of the serous and synovial membranes, also the blood- and lymph-vessels; the outer covering of the skin, or epidermis,[1] is constructed on the same plan. Many gland-ducts, also, are lined with similar epithelium-cells, and the cells in the finest parts of these ducts, and in their extremities and most actively secreting parts, have a similar structure, though they are there usually spheroidal instead of flat.

The second variety is the *cylindrical*, or *conical epithelium*, which extends from the cardiac orifice of the stomach along the whole of the digestive canal to the anus, and lines the various principal gland-ducts which open upon the mucous surface of this tract. It is also found in the greater part of the male genito-urinary apparatus and the gland-ducts connected with it; and lines the urinary passages of the female from the orifice of the urethra to the beginning of the urinary tubules of the kidneys. It is composed of closely set cells of a conical, pyramidal or cylindrical form, whose

[1] In the description of which a further account is given of this form of epithelium.

apices are attached to the mucous membrane, or to flat epithelial cells lying upon it, and whose bases, which are usually terminated by a truncated plane, are free. Each such cell incloses, at nearly mid-distance between its base and apex, a flat nucleus with nucleoli (Fig. 54).

Fig. 54.

Cylinders of the intestinal epithelium, after Henle: A, cylinder from the cardiac region of the human stomach; B, the same from the jejunum; C, cylinders of the intestinal epithelium, as seen when looking on their free extremities; D, ditto, as seen in a transverse section of a villus.

In the third variety of epithelium, cells, similar in other respects to the above, are provided at their free extremities with several fine pellucid pliant processes or cilia, which are constantly in rapid vibratory motion, and the nature of which will be considered hereafter.[1] This form of epithelium lines the whole respiratory tract of mucous membrane and its prolongations. It occurs also in the female generative apparatus, commencing about the neck of the uterus, and extending to the fimbriated extremities of the Fallopian tubes, and for a short distance, along the peritoneal surface of the latter. A tessellated epithelium, with scales partly covered with cilia, lines the interior of the cerebral ventricles.

These various kinds of epithelium serve one general purpose, namely, that of protecting, and, at the same time, rendering smooth, the surfaces on which they are placed. But each also, probably, discharges a special office in relation to the particular function of the mucous membrane on which it is placed; and in relation to the subject more immediately in view—secretion by mucous membranes—it is highly probable that the epithelium-cells, whatever be their forms and other functions, are the organs in which, by a regular process of elaboration and secretion, such as will be presently described, the *mucus* of the several mucous membranes is formed and discharged. The general properties of mucus are already described

[1] See the chapter on MOTION.

(p. 25): the peculiarities characteristic of the mucus of each part are as yet scarcely examined.

SECRETING GLANDS.

The secreting glands are the organs to which the office of secreting is more especially ascribed: for they appear to be occupied with it alone. They all present, amid manifold diversities of form and composition, a general plan of structure, by which they are distinguished from all other textures of the body; especially, all contain and appear constructed with particular regard to the arrangement of the cells, which, as already expressed, both line their tubes or cavities as an epithelium, and elaborate, as secreting cells, the substances to be discharged from them.

According to the different forms in which these cells are arranged, and the mode in which their contents are discharged, so are the several varieties of glands constructed and arranged in classes. In some, a single primary vesicle or sacculus, containing cells and nuclei, constitutes the whole gland; and such a sacculus, having elaborated materials into its cavity, discharges them by the absorption or dehiscence of its walls, and then disappears. This constitutes the class of *temporary* glands, or glands *without permanent orifices:* examples of which are furnished by the Peyer's and solitary glands of the intestines (p. 187), the lenticular glands occasionally met with along the lesser arch of the stomach (p. 167), and the similar glands sometimes seen imbedded in the mucous membranes of the pharynx, œsophagus, and urinary bladder. The Graafian vesicles, also, both in structure and in mode of function, present many analogies to this form of glands.

These simple glands seem to serve only a temporary purpose, having discharged which they disappear, and are not reproduced until the occasion for them again arises. Thus, it is sometimes impossible to find the Peyer's and solitary glands of the intestines, and the others are more often absent than not—but in this fact lies their peculiar interest, in relation to the general physiology of secretion; since it is probable that their successive or periodical formation, the maturation of their contents, their discharge and temporary disappearance, represent very nearly the successive changes through which the acini or minutest lobules of the more complex glands pass.

These more complex glands, to which alone, till lately, the name of secreting glands was applied, may, for distinction as a class, be named *permanent glands*, or *glands with permanent ducts*. They comprise the great majority of glands; and for convenience of description may be further divided into three principal groups, the characters of each of which are determined by the different

modes in which the sacculi or tubes containing the secreting cells are grouped.

1. The *simple tubule*, or *tubular gland;* examples of which are furnished by the several tubular follicles in mucous membranes; especially by the follicles of Lieberkühn, in the mucous membrane of the intestinal canal (p. 186), and the tubular or gastric glands of the stomach (p. 166.) These appear to be simple tubular depressions of the mu[illegible] on which they open, each consisting of an elongat[illegible], the wall of which is formed of primary membrane, [illegible] secreting cells arranged as an epithelium. To t[illegible] y be referred the elongated and tortuous sudorip[illegible] ie skin, and the Meibomian follicles beneath the [illegible] tiva; though the latter are made more complex b[illegible] of vesicles along their sides, and form a connecti[illegible] he members of this division and the next, as t[illegible] r length and tortuosity do between these and the third division.

2. The *aggregated glands*, including those that used to be called *conglomerate*, in which a number of vesicles or *acini* are arranged in groups or lobules. Such are all those commonly called mucous glands, as those of the trachea, vagina, and the minute salivary glands. Such, also, are the tonsils, the lachrymal, Brunnian, large salivary and mammary glands, Cowper's and Duverney's glands, the pancreas and prostate: the liver, also, may be included in this class, though the anatomy of its secreting structure is not yet satisfactorily determined. These various organs differ from each other only in secondary points of structure; such as, chiefly, the arrangement of their excretory ducts, the grouping of the *acini* and lobules, their connection by fibro-cellular tissue, and supply of bloodvessels. The acini commonly appear to be formed by a kind of fusion of the walls of several vesicles, which thus combine to form one cavity lined or filled with secreting cells, which also occupy recesses from the main cavity. The smallest branches of the gland-ducts sometimes open into the centres of these cavities; sometimes the acini are clustered round the extremities, or by the sides, of the ducts: but, whatever secondary arrangement there may be, all have the same essential character of rounded groups of vesicles containing gland-cells, and opening, either occasionally or permanently, by a common central cavity into minute ducts, which ducts in the large glands converge and unite to form larger and larger branches, and at length, by one common trunk, open on a free surface of membrane (xxv. 1842, p. 48).

3. The *convoluted tubular glands*, such as the kidney and testis, form another division. These consist of tubules of membrane, lined with secreting cells arranged like an epithelium. Through nearly the whole of their long course, the tubules present an almost uniform

size and structure; ultimately, they terminate either in a *cul-de-sac*, or by dilating, as in the Malpighian capsules of the kidney, or by forming a simple loop and returning, as in the testicle.

Among these varieties of structure, all the permanent glands are alike in some essential points, besides those which they have in common with all truly secreting structures. They agree in presenting a large extent of secreting surface within a comparatively small solid space; in the circumstance that while one end of the gland-duct opens on a free surface, the opposite end is always closed, having no direct communication with bloodvessels, or any other canals; and in an uniform arrangement of capillary bloodvessels, ramifying and forming a network around the walls and in their interstices of the ducts and acini.

PROCESS OF SECRETION.

From what has been said, it will have already appeared that the modes in which secretions are produced are at least two. Some fluids, such as the secretions of serous membranes, appear to be simply exudations or oozings from the bloodvessels, whose qualities are determined by those of the liquor sanguinis, while the quantities are liable to variation, or are chiefly dependent on the pressure of the blood on the interior of the bloodvessels. But in the production of the other secretions, such as those of mucous membranes and all glands, other besides these mechanical forces are in operation. Most of the secretions are indeed liable to be modified by the circumstances which affect the simple exudation from the bloodvessels, and the products of such exudations when excessive are apt to be mixed with the more proper products of all the secreting organs. But the act of secretion in all glands is the result of the vital processes of cells or nuclei, which, as they develop themselves and grow, form in their interior the proper materials of the secretion, and then discharge them.

The best evidence for this view is, 1st. That cells and nuclei are constituents of all glands, however diverse their outer forms and other characters, and are in all glands placed on the surface or in the cavity whence the secretion is poured. 2d. That many secretions which are visible with the microscope, may be seen in the cells of their glands before they are discharged. Thus, bile may be often discerned by its yellow tinge in the gland-cells of the liver; spermatozoids in the cells of the tubules of the testicles; granules of uric acid in those of the kidneys of fish, fatty particles like those of milk in the cells of the mammary gland.

The process of secretion might therefore be said to be accomplished in and by the life of these gland-cells. They appear, like the cells or other elements of any other organ, to develop them-

selves, grow, and attain their individual perfection by appropriating the nutriment from the adjacent bloodvessels and elaborating it into the materials of their walls and the contents of their cavities. In this perfected state they subsist for some brief time, and when that period is over they appear to dissolve or burst and yield themselves and their contents as the peculiar material of the secretion. And this appears to be the case in every part of the gland that contains the appropriate [illegible] herefore not in the extremities of the ducts or in [illegible] but in great part of their length.[1]

In these things there [illegible] semblance between secretion and nutrition; for, if th[illegible] ch the secreting glands are to serve in the economy [illegible], their formation might be considered as only the pro[illegible] ition of organs, whose size and other conditions are ma[illegible], and by means of, the continual succession of cells de[illegible] emselves and passing away. In other words, glands are maintained by the development of the cells, and their continuance in the perfect state: and the secretions are discharged as the constituent gland-cells degenerate and are set free. The processes of nutrition and secretion are similar also, in their obscurity: there is the same difficulty in saying why, out of apparently the same materials, the cells of one gland elaborate the components of bile, while those of another form the components of milk, and of a third those of saliva, as there is in determining why the cells of one tissue form cartilage, of another bone, of a third muscle, or any other tissue. In nutrition, also, as in secretion, some elements of tissues are different in their chemical properties from any of the constituents ready formed in the blood; such are the gelatinous tissues; others, as the muscular, are chiefly composed of fibrine, which appears identical with that in the blood. Of these differences, also, no account can be rendered: but, obscure as the cause of these diversities may be, they are not objections to the explanation of secretion as a process similar to nutrition: an explanation with which all the facts of the case are reconcilable.

It may be observed that the diversities presented by the other constituents of glands afford no explanation of the differences or peculiarities of their several products. There are many differences in the arrangements of the bloodvessels in different glands and mucous membranes; and, in accordance with these, much diversity in the rapidity with which the blood traverses them. But there is no reason for believing that these things do more than influence

[1] Respecting the general anatomy of secreting glands, and the part performed by cells in the process of secretion, see Müller (cxlvii. and xxxii. p. 428, Am. Ed.); Simon (lxix. and xli. vol. xxx.); Bowman (lxxiii. art. *mucous membrane*); Carpenter (lxxiii. art. *Secretion*); Goodsir (ii.); and for a general account of the individual life of cells consult Carpenter (cxxxi.).

the rate of the process and the quantity of the material secreted. *Ceteris paribus*, the greater the vascularity of a secreting organ, and the larger the supply of blood traversing its vessels in a given time, the larger is the amount of secretion; but there is no evidence that the quantity or mode of movement of the blood can determine the quality of the secretion. The various modes and extents in which the basement-membrane is developed in different secreting organs have probably as little influence on the kind of secretion; for each of the several secretions is, in different animals, the product of glandular structures, widely various in their external form; and, on the other hand, very different fluids may be secreted by glands that, in the distribution of their ducts and vessels, are very similar (see especially Müller, xxxii.).

The *discharge of secretions* from glands may take place as soon as they are formed; or the secretion may be long retained within the gland or its ducts. The secretions of glands which are continually in active function for the purification of the blood, such as the kidneys, are generally discharged from the gland as rapidly as they are formed. But the secretions of those whose activity of function is only occasional, such as the testicle, are usually retained in the ducts during the periods of the gland's inaction. And there are glands which are like both these classes, such as the lachrymal and salivary, which constantly secrete small portions of fluid, and on occasions of greater excitement discharge it more abundantly. The modes, as well as the times in which secretions are discharged, are also various, or appear to be so. The glands that have not permanent ducts, *e. g.*, the Peyer's glands (see p. 187), discharge their mature contents by the rupture or absorption of their cell-wall, and of the membrane over them; and, as already stated, it is not improbable that this represents a common mode of discharge, the secretions being first stored up in closed acini or vesicles at the ends, or by the sides, of the minutest ducts, and then opening into these by the absorption of their own walls, and of the adjacent portion of the basement-membrane. But there is no sufficient proof of this; and the more general opinion seems to be, that the secreting cells are always inclosed within the ducts of the glands, or within cells or vesicles that always communicate with the ducts.

When discharged into the ducts, the further course of secretions is effected partly by the pressure from behind; the fresh quantities of secretion propelling those that were formed before. In the larger ducts, its propulsion is assisted by the contractions of their walls. All the larger ducts, such as the ureter and common bile-duct, possess in their coats contractile fibro-cellular tissue, or organic muscular fibres; they contract when irritated, and sometimes manifest peristaltic movements (Müller, xxxii. p. 453, Am. Ed.). It is

probable that a like contractile power extends along the ducts to a considerable distance within the substance of the glands whose secretions can be rapidly expelled. Saliva and milk, for instance, are sometimes ejected with much force; doubtless, by the energetic and simultaneous contraction of many of the ducts of their respective glands. The contraction of the ducts can only expel the fluid they contain through their main trunk; for at their opposite ends all the ducts are closed. [illegible] probable that the fibres of gland-ducts may be af[illegible]d of spasm, or may be paralyzed; either conditio[illegible]ed by an impeded discharge of the secretion.

Circumstances influenc[illegible].—The influence of external conditions on the funct[illegible] of [illegible]ds is manifested chiefly in alterations of the quan[illegible]n: and among the principal of these conditions are [illegible] he quantity of blood, in the quantity of the peculiar materials for any secretion that it may contain, and in the conditions of the nerves of the glands.

In general, an increase in the quantity of blood traversing a gland coincides with an augmentation of its secretion. Thus, the mucous membrane of the stomach becomes florid, when, on the introduction of food, its glands begin to secrete: the mammary gland becomes much more vascular during lactation; and it appears that all circumstances which give rise to an increase in the quantity of material secreted by an organ, produce coincidently an increased supply of blood. In most cases, the increased supply of blood rather follows than precedes the increase of secretion; as, in the nutritive processes, the increased nutrition of a part just precedes and determines the increased supply of blood; but, as also in the nutritive process, an increased supply of blood may have, for a consequence, an increased secretion from the glands to which it is sent.

Glands also secrete with increased activity when the blood contains more than usual of the materials they are designed to separate. Thus, when an excess of urea is in the blood, whether from excessive exercise or from destruction of one kidney, a healthy kidney will excrete more than it did before. It will at the same time grow larger; an interesting fact, as proving both the identity of secretion and nutrition in glands, and that the presence of certain materials in the blood may lead to the formation of structures in which they may be incorporated.

The production of secretions often appears, also, to be influenced by the condition of the nervous system. It is not possible to say with certainty whether the secretion of a gland would be arrested by the division or destruction of all the nerves distributed to it, for the branches of these nerves are largely spread over the blood-

vessels, so that their destruction cannot be effected without serious injury to the vessels. The most distinct instances of nervous influence are shown in cases of secretion of the earthy phosphates by the kidneys after injury of the spinal cord. Whatever, within certain limits, excites the nerves of a gland is followed by an increase in the quantity of its secretion. This is illustrated in the flow of tears and the increased discharge of saliva which often accompany a paroxysm of neuralgia in the fifth pair of nerves.

It appears immaterial to the perfection of secretion from which nervous centres a secreting organ receives its supply of nervous influence; for some glands are supplied with sympathetic, others with cerebro-spinal nerves, and others with both kinds; yet the mode of secretion appears to be in all alike.

The mode in which the nervous system influences secretion is quite obscure. In many cases it probably exerts its influence by increasing or diminishing the quantity of blood supplied to the secreting gland, in virtue of the power which it exercises over the contractility of the smaller bloodvessels. Its influence over secretion, as well as over other functions of the body, may be excited by causes acting directly upon the nervous centres, upon the nerves going to the secreting organ, or upon the nerves of other parts. In the latter case a reflex act is produced: thus, the impression produced upon the nervous centres by the contact of food in the mouth is supposed to be reflected upon the nerves supplying the salivary glands, to produce through these a more abundant secretion of saliva.

Through the nerves, various conditions of the mind also influence the secretions. Thus, the thought of food may be sufficient to excite an abundant flow of saliva. And probably, it is the mental state which excites the abundant secretion of urine in hysterical paroxysms, as well as the perspirations and occasional diarrhœa, which ensue under the influence of terror, and the tears excited by sorrow or excess of joy. The quality of a secretion may also be affected by the mind; as in the cases in which, through grief or passion, the secretion of milk is altered, and is sometimes so changed as to produce irritation in the alimentary canal of the child, or even death.[1]

The secretions of some of the glands seem to bear a certain relation, or antagonism, to each other, by which an increased activity of one is usually followed by diminished activity of one or more of the others, and a deranged condition of one is apt to entail a disordered state in the others. Such relations appear to exist among the various mucous membranes: and the close relation between the secretion of the kidney and that of the skin is a subject of constant observation.

[1] See such cases by Carpenter (cxxxi. p. 945), 7th Am. Ed.

CHAPTER XII.

VASCULAR GLANDS: OR GLANDS WITHOUT DUCTS.

THE materials s[illegible]lood by the ordinary proces[illegible] of secretion by gl[illegible]charged from the organ in which they are for[illegible]r straightway expelled from the body, or if the[illegible]d into the blood, it is only after they have been[illegible] original condition, as in the cases of the saliva[illegible] appears, however, to be a modification of the p[illegible], in which certain materials are abstracted from t[illegible] some change, and are added to the lymph or restored to the blood, without being previously discharged from the secreting organ, or made use of for any secondary purpose. The bodies in which this modified form of secretion takes place are usually described as vascular glands, or glands without ducts, and include the spleen, the thymus and thyroid glands, and the supra-renal capsules.

The evidence in favor of the view that these organs exercise a function analogous to that of secreting glands has been chiefly obtained from recent investigations into their structure, which have shown that all the glands without ducts contain the same essential structures as the secreting glands, except the ducts. They are mainly composed of vesicles or sacculi, either simple and closed, as in the thyroid (Simon, lxix., Am. Ed.), spleen, and suprarenal capsules (Ecker, lxx.), or variously branched, and with the cavities of the several branches communicating in and by common canals, as in the thymus (Simon, lxix.[1] Am. Ed.). These vesicles, like the acini of secreting glands, are formed of a delicate homogeneous membrane, are surrounded with a vascular plexus, and are filled with finely molecular albuminous fluid, suspended in which are either granules of fat, or cytoblasts or nuclei, or nucleated cells, or a mixture of all these.

[1] For all relating to the minute structure and functions of the vascular glands, consult the important works of the two above-mentioned authors, and of Œsterlen (cli.), and Kölliker (lxxiii. art. *Spleen*). See also Dr. Julius Evans on the Structure of the Spleen (xxx. 1844). For the rough anatomy, consult Müller (xxxii. p. 413, Am. Ed.;) and, for what relates to the fluids contained in the several glands, Gulliver (xxviii.). Ecker's work on the suprarenal capsules is translated into the London Medical Gazette, May, 1848; and for an abstract of Œsterlen's observations, see xxv. 1844–5, p. 28. [The student may also consult, with advantage, the article on the "Ductless Glands," in Carpenter's Human Physiology, p. 456, 5th Am. Ed.]

These general resemblances in structure between the vascular glands and the true secernent glands lead to the supposition that both sets of organs pursue, up to a certain point, a similar course in the discharge of their functions. It is assumed that certain principles in an inferior state of organization are effused from the vessels into the æsculi, and gradually develop themselves into nuclei or cytoblasts, which may be further developed into cells; that, in the growth of these nuclei and cells, the materials derived from the blood are elaborated into a higher condition of organization; and that, when liberated by the dissolution of the cells, they pass into the lymphatics, or are again received into the blood, whose aptness for nutrition they contribute to maintain.

The opinion that the vascular glands thus serve for the higher organization of the blood, is supported by their being all especially active in the discharge of their functions during fœtal life and childhood, when, for the development and growth of the body, the most abundant supply of highly organized blood is necessary. The bulk of the thymus gland, in proportion to that of the body, appears to bear almost a direct proportion to the activity of the body's development and growth, and when, at the period of puberty, the development of the body may be said to be complete, the gland wastes and finally disappears. The thyroid gland and renal capsules, also, though they probably never cease to discharge some amount of function, yet are proportionally much smaller in childhood than in fœtal life and infancy; and with the years advancing to the adult period, they diminish yet more in proportionate size and apparent activity of function. The spleen more nearly retains its proportionate size, and enlarges nearly as the whole body does.

The function of the vascular glands seems not essential to life, at least in the adult. The thymus wastes and disappears; no signs of illness attend some of the diseases which wholly destroy the structure of the thyroid gland; and the spleen has been often removed in animals, and in a few instances in men, without any evident ill-consequence. It is possible that, in such cases, some compensation for the loss of one of the organs may be afforded by an increased activity of function in those that remain. The experiment, to be complete, should include the removal of all these organs, an operation hardly possible without immediate danger to life. Nor, indeed, would this be certainly sufficient, since there is some reason to suppose that the duties of the spleen, after its removal, might be performed by lymphatic or lacteal glands, between whose structure and that of the vascular glands there is much resemblance, and which, it is said, have been found peculiarly enlarged when the spleen has been removed (Mayer, lxxxviii. March, 1845).

Although the functions of all the vascular glands may be similar, in so far as they may all alike serve for the elaboration and main-

tenance of the blood, yet each of them probably discharges a peculiar office, in relation either to the whole economy, or to that of some other organ. The *spleen*, from the readiness with which it admits of being distended, and from the fact that it is generally small while gastric digestion is going on, and enlarges when that act is concluded, is supposed to act as a kind of vascular reservoir, or diverticulum to the portal system or more particularly to the vessels of the stomach. serve such a purpose is also made probable by the c nich it undergoes in certain affections of the heart a ded with obstruction to the passage of blood through rgan, and by its diminution when the congestion am is relieved by discharges from the bowels, or lood into the stomach. But it can hardly be sup rgan of so great complexity as the spleen, cont er structures besides blood-vessels, a mechanic circulation should, be more than a very subordinate part of the office in the economy. And the same objection lies against the opinion that the thyroid gland is important as a diverticulum for the cerebral circulation, or the thymus for the pulmonary in childhood. These, also, like the spleen, must have peculiar and higher, but as yet unknown offices. Respecting the special office of the thyroid gland, nothing reasonable can be suggested; nor is there any evidence concerning that of the renal capsules. Respecting the thymus gland, the observations of Mr. Simon (lxix)., have shown that in the hybernating animals, in which it exists throughout life, as each successive period of hybernation approaches, the thymus greatly enlarges and becomes laden with fat, which accumulates in it and in fat-glands connected with it, in even larger proportion than it does in the ordinary seats of adipose tissue. Hence it appears to serve for the storing up of materials which, being reabsorbed in the inactivity of the hybernating period, may maintain the respiration and the temperature of the body in the reduced state to which they fall during that time.

CHAPTER XIII.

THE SKIN AND ITS SECRETIONS.

To complete the consideration of the processes of organic life, and especially of those which, by separating materials from the blood, maintain it in the state necessary for the nutrition of the body, a part of the physiology of the skin must be now considered: for

besides the several purposes which it serves, as an external integument for the protection of the deeper tissues, and as a sensitive organ in the exercise of tact or touch, it is also an important excretory and absorbing organ; and of all its functions, that of excretion is the most directly necessary to the maintenance of life. Its office as a sensitive integument will be considered in the chapter on Touch: here, it will be regarded chiefly in relation to its functions of excretion and absorption.

Structure of the Skin.

The skin consists, principally, of a peculiar layer of vascular tissue, named the *corium*, *derma* or *cutis vera*, and an external covering of epithelium, termed the *cuticle* or *epidermis*. Within and beneath the corium are imbedded several organs with special functions, namely, sudoriparous glands, hair follicles, and sebaceous glands; and on its surface are sensitive papillæ.

The *corium* or *cutis*, which rests upon a layer of adipose and cellular tissue of varying thickness, is a dense and tough, but yielding and highly elastic, structure composed of fasciculi of fibro-cellular tissue, interwoven in all directions, and forming, by their interlacements, numerous spaces or areolæ. These areolæ are large in the deeper layers of the cutis, and are there usually filled with little masses of fat: but, in the more superficial parts they are exceedingly small or entirely obliterated.

The *papillæ* are minute conical or cylindriform elevations, which are more prominent and more densely set at some parts, as the palmar surface of the hands and fingers, than at others (Fig. 55). On these parts, and on the plantar surface of the feet and toes, they are disposed in double rows, in parallel curved lines separated from each other by depressions. Thus they may be seen easily on the palm; whereon each raised line is composed of a double row of papillæ, and is intersected by short transverse lines or furrows corresponding with the interspaces between the successive pairs of the papillæ.

In the middle of each of these transverse furrows, and irregularly scattered between the bases of the papillæ in other parts of the surface of the body, are the orifices of ducts of the *sudoriparous glands*, by which it is probable that a large portion of the aqueous and gaseous materials excreted by the skin are separated. Each of these glands consists of a small lobular mass, which appears formed of a coil of tubular gland-duct, surrounded by blood-vessels and imbedded in the subcutaneous adipose tissue (Fig. 55). From this mass the duct ascends, for a short distance, in a spiral manner through the deeper part of the cutis; then passing straight, and then sometimes again becoming spiral, it passes through the

cuticle and opens by an oblique valve-like aperture. In the parts where the epidermis is thin, the ducts themselves are thinner and more nearly straight in their course. The canal of the duct, which maintains nearly the same diameter throughout, is lined with a

Fig. 55.

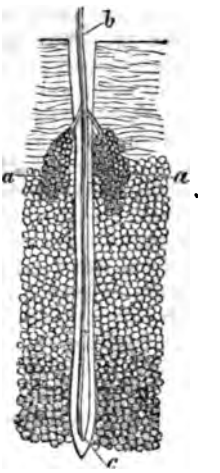
A perpendicular section of the skin of the sole of the foot, showing: 1. The salient lines of the external surface of the skin cut perpendicularly. 2. The furrows or wrinkles of the same. 3. The epidermis or cuticle, as formed by its superimposed layers. 4. The rete mucosum. 5. The cutis vera, with its cellular fibres pressed into fasciculi and each directed towards the papillæ. 6. The papillæ, each of which answers to the prominences on the external surface of the skin. 7. The small furrows between the papillæ. 8. The deeper furrows which are between each couple of the papillæ. 9. Cells filled with fat, and seen between the bands of fibres. 10. The adipose layer with numerous fat vesicles. 11. Cellular fibres of the adipose tissue, continuous with the sub-cutaneous cellular tissue, and with that of the cutis vera. 12. The sudoriferous follicles. 13. The spiral or sudoriferous canals. 14. The infundibular shaped pores or orifices of these canals.

layer of epithelium continuous with the epidermis; and its walls are formed of pellucid membrane continuous with the surface of the cutis.

The sudoriparous glands are abundantly distributed over the whole surface of the body, but are especially numerous, as well as very large, in the skin of the palm of the hand, where, according to Krause, they amount to 2736 in each superficial square inch (xv. article *Haut*), and according to Mr. Erasmus Wilson to as many as 3528 (xxxv.). They are almost equally abundant and large in the skin of the sole. The glands by which the peculiar odorous

r of the axillæ is secreted form a nearly complete layer under utis, and are like the ordinary sudoripa- glands, except in being larger and having short ducts (Robin, xix. Sept. 1845; ier, xxxvi. Jan. 1846). In the neck and , where they are least numerous, the ls amount to 417 on the square inch use). Their total number Krause esti- s at 2,381,248; and, supposing the ori- of each gland to present a surface of th of a line in diameter, he reckons that whole of the glands would present an orating surface of about eight square es.

Fig. 56.



Sebaceous glands of the skin, after Gurlt: *a*, *a*, sebaceous glands, opening into the follicle of the hair by efferent ducts; *b*, a hair on its follicle.

esides the perspiration, the skin secretes eculiar fatty matter, and for this purpose ovided with another set of special organs, ned *sebaceous glands* (Fig. 56), which, the sudoriparous glands, are abundantly ributed over most parts of the body. y are most numerous in parts largely sup- d with hair, as the scalp and face, and are kly distributed about the entrance of the ous passages into the body, as the anus, , lips, and external ear. They are en- ly absent from the palmar surfaces of the ds and the plantar surfaces of the feet. y are minutely lobulated glands, which ear composed of an aggregate of small vesicles or sacculi filled h opaque white substance, like soft ointment.[1] Minute capillary sels overspread them; and their ducts, which have a beaded ap- rance, as if formed of rows of cells, open either on the surface the skin close to a hair, or, which is more usual, directly into follicle of the hair. In the latter case, there are generally two ds to each hair (Fig. 56). The ducts of these glands are very monly tenanted by one or more entozoa, of a species named rus folliculorum. (Erasmus Wilson, xliii. 1844, p. 305; Gruby, ii. March 1845.)

The *hair-follicles*, into which the sebaceous glands open, may be reckoned among the secreting organs of the skin, since it only at their lowest part that the material produced from their ls is appropriated to the growth of hair. The follicles are

[1] The peculiar bitter yellow substance secreted by the skin of the external itory passage is named *cerumen*, and the glands themselves *ceruminous* ds; but they do not differ in structure from the other sebaceous glands.

tubular depressions from the surface of the skin, descending into the subcutaneous fat, generally to a greater depth than the sudoriparous glands, and at their deepest part enlarging in a bulbous form, and often curving from their previous rectilinear course. They are lined throughout with cells of epithelium, continuous with those of the epidermis, and their walls are formed of pellucid membrane, which, commonly, in the follicles of the largest hairs, has the structure of [illegible]lar tissue. The cells lining the deepest part of [illegible]ibute to the growth of the hair; those [illegible], though like epithelial-cells in their ar[illegible] gland-cells in function, and secrete a pa[illegible] h the hairs and the surface of the skin are anoin[illegible]

Such are the glan[illegible]but it is with it, as with the glands in general; t[illegible]ormed secretions, fluids pass through it by mere [illegible] bloodvessels, and gases and watery vapor are exhaled [illegible] surface. This evaporation, however, is much limited by the *epidermis*, which is composed of layers of tessellated or pavement-epithelium cells. Its cells are flattened, oval, or polygonal, and average about 1-1900th of an inch in diameter; each contains a nucleus, which again contains one or more distinct, and several paler granules. The thickness of the epidermis on different portions of the skin, is directly proportioned to the friction, pressure, and other sources of injury to which it is exposed; and the more it is subjected to such injury, within certain limits, the more does it grow, and the thicker and more horny does it become; for it serves as well to protect the sensitive and vascular cutis from injury from without, as to limit the evaporation of fluid from the bloodvessels. The adaptation of the epidermis to the latter purpose, may be well shown by exposing to the air two dead hands or feet, of which one has its epidermis perfect, and the other is deprived of it; in a day, the skin of the latter will become brown, dry, and horn-like, while that of the former will almost retain its natural moisture.

Excretion by the Skin.

The skin, as already stated, is the seat of a twofold excretion; of that formed by the sebaceous glands and hair-follicles, and of the more watery fluid, the sweat or perspiration, eliminated by the sudoriparous glands.

The secretion of the sebaceous glands and hair-follicles (for their products cannot be separated) consist of cast-off epithelium cells, with nuclei and granules, together with an oily matter, extractive

[1] On the Structure of the Skin and its Glands, see **Breschet (xlv.)**; Henle (xxxvii.); E. Wilson (xliv.); Todd and Bowman (**xxxix.**), and other works on General Anatomy.

matter, and stearine; in certain parts, also, it is mixed with a peculiar odorous principle. It is, perhaps, nearly similar in composition to the unctuous coating, or vernix caseosa, which is formed on the body of the fœtus while in the uterus, and which contains large quantities, both of oleine and margarine (J. Davy, xli. vol. xxvii. p. 187). Its purpose seems to be that of keeping the skin moist and supple, and, by its oily nature, of both hindering the evaporation from the surface, and guarding the skin from the effects of the long-continued action of moisture. But while it thus serves local purposes, its removal from the body entitles it to be reckoned among the excretions of the skin; though the share it has in the purifying of the blood, cannot be discerned.

The fluid secreted by the sudoriparous glands is usually formed so gradually that the watery portions of it escape by evaporation as fast as it reaches the surface. But, during strong exercise, exposure to great external warmth, in some diseases, and when evaporation is prevented by the application of oiled silk or plaster, the secretion becomes more sensible and collects on the skin in the form of drops of fluid. A good analysis of the secretion of these glands, unmixed with other fluids secreted from the skin, can scarcely be made; for the quantity that can be collected pure is very small. Krause (iv.) in a few drops from the palm of the hand found an acid reaction, oily matter, and margarine, with water, and no other examination has been made.

The perspiration of the skin, as the term is commonly employed in physiology, includes all that portion of the secretions and exudations from the skin that is capable of evaporation; the sweat includes all that may be collected in drops of fluid on the surface of the skin. The former is also often called insensible perspiration: the latter, sensible perspiration. The fluids are the same, except that the sweat is commonly mingled with various substances lying on the surface of the skin. The contents of the sweat are, in part, matters capable of assuming the form of vapor, such as carbonic acid and water, and in part, other matters which are deposited on the skin, and mixed with the sebaceous secretion. Thenard collected the perspiration in a flannel shirt which had been washed in distilled water, and found in it chloride of sodium, acetic acid, some phosphate of soda, traces of phosphate of lime, and oxide of iron, together with an animal substance. In sweat which had run from the forehead in drops, Berzelius found lactic acid, chloride of sodium, and muriate of ammonia (xxiv). Anselmino placed his arm in a glass cylinder, and closed the opening around it with oiled silk, taking care that the arm touched the glass at no point. The cutaneous exhalation collected on the interior of the glass, and ran down as a fluid: on analyzing this, he found water, acetate of ammonia, and carbonic acid; and in the ashes of the dried residue

of sweat he found carbonate, sulphate, and phosphate of soda, and some potash, with chloride of sodium, phosphate and carbonate of lime, and traces of oxide of iron. But of these several substances none need particular consideration except the carbonic acid and water.

The quantity of watery vapor excreted from the skin was estimated very carefully by Lavoisier and Seguin. The latter chemist inclosed his body in [illegible], with a mouth-piece. The bag being closed by [illegible]bove, and the mouth-piece adjusted and gummed [illegible]round the mouth, he was weighed, and then [illegible] several hours, after which time he was again [illegible]ference in the two weights indicated the amount [illegible]onary exhalation. Having taken off the air-tight [illegible] immediately weighed again, and a fourth time, aft[illegible]val. The difference between the two weights last [illegible]he amount of the cutaneous and pulmonary exhalation together; by subtracting from this the loss by pulmonary exhalation alone while he was in the air-tight dress, he ascertained the amount of cutaneous transpiration. The repetition of these experiments during a long period, showed that during a state of rest the average loss by cutaneous and pulmonary exhalation in a minute is from seventeen to eighteen grains—the minimum eleven grains, the maximum thirty-two grains; and that of the eighteen grains, eleven pass off by the skin, and seven by the lungs. The maximum loss by exhalation, cutaneous and pulmonary, in twenty-four hours, is 5 lbs.; the minimum, 1 lb. 11 oz. 4 dr. (xlii. 1790). Valentin found the whole quantity lost by exhalation from the cutaneous and respiratory surfaces of a healthy man, who consumed daily 40,000 grains of food and drink, to be 19,000 grains, or 3½ lbs. Subtracting from this, for the pulmonary exhalation, 5000 grains, and for the excess of the weight of the exhaled carbonic acid over that of the equal volume of the inspired oxygen, 2256 grains, the remainder, 11,744 grains, or about 2½ lbs., may represent an average amount of cutaneous exhalation in the day.

The large quantity of watery vapor thus exhaled from the skin, will prove that the amount excreted by simple transudation through the cuticle must be very large, if we may take Krause's estimate of about eight square inches for the total evaporating surface of the sudoriparous glands; for not more than about 3365 grains could be evaporated from such a surface in twenty-four hours, under the ordinary circumstances in which the surface of the skin is placed (xxv. 1843–4, p. 40). This estimate is not an improbable one, for it agrees very closely with that of Milne Edwards, who calculated that when the temperature of the atmosphere is not above 68° F., the glandular secretion of the skin contributes only 1-6th to the total sum of cutaneous exhalations (xlvi).

The quantity of watery vapor lost by transpiration, is of course influenced by all external circumstances which effect the exhalation from other evaporating surfaces, such as the temperature, the hygrometric state, and the stillness, of the atmosphere. But, of the variations to which it is subject under the influence of these conditions, no calculation has been yet made.

Neither, until recently, has there been any estimate of the quantity of carbonic acid exhaled by the skin on an average, or in various circumstances. Regnault and Reiset have attempted to supply this defect, and conclude, from some careful experiments, that the quantity of carbonic acid generated by the body of a warm-blooded animal is about 1-50th of that furnished by the pulmonary respiration (liii. 1849). The cutaneous exhalation is most abundant in the lower classes of animals, more particularly the naked Amphibia, as frogs and toads, whose skin is thin and moist, and readily permits an interchange of gases between the blood circulating in it and the surrounding atmosphere. Bischoff found that, after the lungs of frogs had been tied and cut out, about a quarter of a cubic inch of carbonic acid gas continues to be exhaled by the skin. And this quantity is very large, when it is remembered that a full-sized frog will generate only about half a cubic inch of carbonic acid by his lungs and skin together in six hours (Milne Edwards and Müller, xxxii. p. 207. Am. Ed.). That the respiratory function of the skin is perhaps even more considerable in the higher animals than appears to be the case from the experiments of Regnault and Reiset just alluded to, is made probable by the fact observed by Fourcault (xviii. March, 1844), Magendie (xix. Dec. 1843), and others, that if the skin is covered with an impermeable varnish, or the body inclosed, all but the head, in a caoutchouc dress, animals soon die, as if asphyxiated; their heart and lungs being gorged with blood, and their temperatures during life gradually falling many degrees, and sometimes as much as 36° F. below the ordinary standard (Magendie). Results so serious as these could not be consequent on the retention of water alone, for that might be discharged through the kidneys and lungs, or some other internal surface.

Absorption by the skin has been already mentioned, as an instance in which that process is most actively accomplished. Metallic preparations rubbed into the skin have the same action as when given internally, only in a less degree. Mercury applied in this manner exerts its specific influence upon syphilis, and excites salivation; potassio-tartrate of antimony may excite vomiting, or an eruption extending over the whole body; and arsenic may produce poisonous effects. Vegetable matters also, if soluble, or already in solution, give rise to their peculiar effects, as cathartics, narcotics, and the like, when rubbed into the skin. The effect of rubbing is

probably to convey the particles of the matter into the orifices of the glands, whence they are more readily absorbed than they would be through the epidermis. When simply left in contact with the skin, substances, unless in a fluid state, are seldom absorbed.

It has long been a contested question whether the skin covered with its epidermis has the power of absorbing water, and it is a point the more difficult to determine, because the skin loses water by evaporation. But fro many experiments it may now be regarded as a fact that such absorption really occurs. M. Edw hat the absorption of water by the surface of the bo ace in the lower animals very rapidly. Not only ve a thin skin, but lizards, in which the cuticle is thi an, after having lost weight by being kept for some atmosphere, were found to recover both their w ess very rapidly when immersed in water. \ the tail, posterior extremities, and posterior part of the body of the lizard were immersed, the water absorbed was distributed throughout the system (xlvi.). And a like absorption through the skin, though to a less extent, may take place also in man.

Dr. Madden, having ascertained the loss of weight by cutaneous and pulmonary transpiration that occurred during half an hour in the air, entered the bath, and remained immersed during the same period of time, breathing through a tube which communicated with the air exterior to the room. He was then carefully dried and again weighed. Twelve experiments were performed in this manner; and in ten there was a gain of weight, varying from 2 scruples to 5 drachms and 1 scruple, or a mean gain of 1 drachm, 2 scruples, and 13 grains. The loss in the air during the same length of time (half an hour), varied in ten experiments from 2½ drachms to 1 ounce 2½ scruples, or, in the mean, was about 6½ drachms. So that, admitting the supposition that the cutaneous transpiration was entirely suspended, and estimating the loss by pulmonary exhalation at 3 drachms, there was in these ten experiments of Dr. Madden an average absorption of 4 drachms 1 scruple and 3 grains, by the surface of the body, during half an hour (xlvii). In four experiments performed by M. Berthold, the gain in weight was greater than in those of Dr. Madden (lxxx. 1838, p. 177).

In severe cases of dysphagia, when not even fluids can be taken into the stomach, immersion in a bath of warm water or of milk and water may assuage the thirst: and it has been found in such cases that the weight of the body is increased by the immersion. Sailors, also, when destitute of fresh water, find their urgent thirst allayed by soaking their clothes in salt water and wearing them in

ate; but these effects may be in part due to the hindrance to aporation of water from the skin.

absorption, also, of different kinds of gas by the skin is l by the experiments of Abernethy, Cruikshank, Beddoes, hers. In these cases, of course, the absorbed gases combine he fluids, and lose the gaseous form. Several physiologists observed an absorption of nitrogen by the skin: Beddoes hat he saw the arm of a negro become pale for a short time immersed in chlorine; and Abernethy observed that when ld his hands in oxygen, nitrogen, carbonic acid, and other contained in jars over mercury, the volume of the gases became lerably diminished.

e share which the evaporation from the skin has in the maince of the uniform temperature of the body, and as one of the tions to which the production of heat needs to be adapted, is ly mentioned (p. 153).

CHAPTER XIV.

THE KIDNEYS AND THEIR SECRETION.

Structure of the Kidneys.

IE kidneys, provided especially for the excretion of the refuse gen, phosphorus and sulphur, lime and magnesia, have the ral structures of glands arranged in a manner distinguishing i from all other excretory organs. In each kidney numerous eting tubes (*tubuli uriniferi*) are collected in bundles, in from :o twenty separated conical or pyramidal portions (*pyramids* or *of Malpighi*), which together constitute the tubular portion ie kidney. The apices of the cones converge, and project into es, which are branches of a large cavity called the *pelvis* of the ey, that leads to the ureter, its excretory duct (Fig. 57). The ks of the urine-tubes open at the extremities or *papillæ* of the mids, and their branches running in straight and somewhat rgent course towards the surface of the kidney, as they apch it, become tortuous, and, winding in various directions, terate in, or bear on small pedicles proceeding from their walls, ed, flask-shaped sacculi, named *capsules of Malpighi*. Those bear capsules at their sides, probably unite with one another ops, or terminate in simply closed ends.

Fig. 57.

A section of the Kidney, surmounted by the suprarenal capsule; the swellings upon the surface mark the original constitution of the organ, as made up of distinct lobules.—1. The suprarenal capsule. 2. The vascular portion of the kidney. 3, 3. Its tubular portion, consisting of cones. 4, 4. Two of the papillæ projecting into their corresponding calyces. 5, 5, 5. The three infundibula; the middle 5 is situated in the mouth of a calyx. 6. The pelvis. 7. The ureter.

The small branches of the renal arteries ramify very abundantly in the parts of the kidney near its surface, and between the several pyramids; and predominating over the tubules, have obtained for these *cortical* parts of the kidney the name of *vascular portion*. ling into capillaries, they r tufts or little balls, called *orpuscles* or *glomerules*. In n of these, each minute s into four or more small nches, which run on the he corpuscles, and give off es that fill up the spaces within them, and lead to a which usually emerges from the corpuscles at the same part as the artery enters it. Thus, each Malpighian corpuscle appears as if suspended by a small short pedicle, formed of its artery and vein. Each lies within a Malpighian capsule, or attached to its exterior (Hyrtl, lxxxviii. April, 1846; Bidder, lxxx. 1845), and from the vein of each proceed capillaries, which ramify in close networks over the urine-tubes (Fig. 58). Thus, therefore, the circulation of the kidney is peculiar in that the capillaries, from which the blood is chiefly derived to form the urine, are like the divisions of a vein rather than of an artery: for the branchings of the arteries in the Malpighian tufts or corpuscles, and the collection of their branches again into the small efferent vessels, give that vessel the character of a vein, and make the capillary circulation over the urine-tubes analogous to the portal circulation through the liver, an analogy which is the closer, because in fish and Amphibia the kidney receives not only a renal artery, whose branches form the Malpighian bodies, but also a large renal (or *renal-portal*) vein, bringing, for the secretion of urine, the venous blood of the hinder parts of the body, and giving off the capillaries which ramify upon the urine-tubes (Bowman, xliii. 1842).

The urine-tubes are minute canals of about 1-700th of an inch in diameter, formed of pellucid, simple, or basement-membrane, and lined throughout with nucleated gland-cells, arranged like an epithelium, of spheroidal form, and darkly dotted or granulated

(see Fig. 59). Not unfrequently, portions of tubes, especially of those that are convoluted or tortuous, appear nearly filled with such cells, or thin separated nuclei, as if the urine were filtered

Fig. 58.

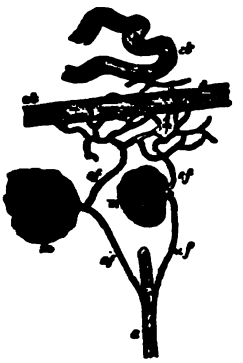


Fig. 59.

Fig. 58. Distribution of the Renal vessels, from Kidney of Horse: *a*, branch of Renal artery; *a f*, afferent vessel; *m*, *m*, Malpighian tufts; *e f*, *e f*, efferent vessels; *p*, vascular plexus surrounding the tubes; *st*, straight tube; *ct*, convoluted tube. Magnified about 30 diameters.

Fig. 59. A, Portion of a secreting canal from the cortical substance of the kidney. B, The epithelium or gland-cells, more highly magnified (700 times). C, Portion of a canal from the medullary substance of the kidney. At one part the basement-membrane has no epithelium lining it.

through them in its way to the pelvis. The same kind of epithelium is continued into the Malpighian capsules, and lines their whole internal surface, and, if they contain Malpighian tufts, is reflected over them like a serous membrane.[1]

Secretion of Urine.

The separation of urine from the blood is probably effected, like other secretions, by the agency of the gland-cells, and equally in all parts of the urine-tubes. The urea and uric acid, and perhaps some of the other constituents existing ready formed in the blood,

[1] In the frog, triton, and probably most or all other naked Amphibia, the epithelium at and just within the neck or commencing dilatation of the Malpighian capsule is ciliated. This fact (first observed by Mr. Bowman) is, perhaps, connected with the peculiar arrangement of the seminal tubes or branches of the vasa deferentia, which open into one end of the Malpighian capsules, while the urine-tubes open into the others. The cilia work towards the seminal tubes, and would prevent the seminal fluid from mingling with the urine (see Bidder, cliv., and Ludwig, lix. 1847).

may need only separation, that is, they may pass from the blood to the urine without further elaboration; but this is not the case with some of the other principles of the urine, such as the acid phosphates and the sulphates, for these salts do not exist in the blood, and must be formed by the chemical agency of the cells.

The large size of the renal arteries and veins permits so rapid a transit of the blood through the kidneys, that the whole of the blood is purified by the [illegible]ion of urine is rapid in comparison with other se[illegible] each portion is secreted it propels those alre[illegible]rds into the pelvis. Thence through the urete[illegible] into the bladder, into which its rate and mode [illegible]n watched in cases of ectopia vesicæ, *i.e.*, of such fissure[illegible]nterior and lower part of the walls of the abdomen, an[illegible]ront wall of the bladder, that its hinder wall with the o[illegible] the ureters is exposed to view. The best observations on [illegible]se were made by Mr. Erichsen (lxxi. 1845). The urine does not enter the bladder at any regular rate, nor is there a synchronism in its movement through the two ureters. During fasting, two or three drops enter the bladder every minute, each drop as it enters first raising up the little papilla on which, in these cases, the ureter opens, and then passing slowly through its orifice, which at once again closes like a sphincter. In the recumbent posture, the urine collects for a little time in the ureters, then flows gently, and if the body is raised, runs from them in a stream till they are empty. Its flow is increased in deep inspiration, or straining, and in active exercise, and in fifteen or twenty minutes after a meal.

The same observations, also, showed how fast some substances pass from the stomach through the circulation, and through the vessels of the kidneys. Ferrocyanate of potash so passed on one occasion in a minute: vegetable substances, such as rhubarb, occupied from sixteen to thirty-five minutes; neutral alkaline salts with vegetable bases, which were generally decomposed *in transitu*, made the urine alkaline in from twenty-eight to forty-seven minutes. But the times of passage varied much; and the transit was always slow when the substances were taken during digestion.

The urine collecting in the urinary bladder is prevented from regurgitation into the ureters by the mode in which they pass through the walls of the bladder, namely, by their lying for between half and three-quarters of an inch between the muscular and mucous coats, and then turning rather abruptly forwards, and opening through the latter. It collects till the distension of the bladder is felt either by direct sensation, or, in ordinary cases, by a transferred sensation at and near the orifice of the urethra. Then, the effort of the will being directed primarily to the muscles of the abdomen, and through them (by reason of its tendency to act with

them, to the urinary bladder), the latter, though its muscular walls are really composed of involuntary muscle, contracts, and expels the urine. The muscular fibres behind the ureters, where they lie between the muscular and mucous coat of the bladder, compress these canals as they contract for the expulsion of the urine; and the vesical orifice of the urethra, which appears to be closed only by the elasticity of the surrounding parts, is forced open by the pressure of the urine while the bladder is contracting, and again closes by the same elasticity when the bladder ceases to contract.

The Urine: its general Properties.

Healthy urine is a clear limpid fluid, of a pale yellow or amber color, with a peculiar faint aromatic odor, which becomes pungent and ammoniacal when decomposition takes place. The urine, though usually clear and transparent at first, often, as it cools, becomes opaque and turbid from the deposition of part of its constituents previously held in solution; and this may be consistent with health, though it is only in disease that, in the temperature of 98° or 100°, at which it is voided, the urine is turbid even when first expelled. Although ordinarily of a pale amber color, yet, consistently with health, the urine may be nearly colorless, or of a brownish or deep orange tint; and between these extremes it may present every shade of color.

When secreted, and, most commonly, when first voided, the urine has a distinctly acid reaction in man and all carnivorous animals, and it thus remains till it is neutralized or made alkaline by the ammonia developed in it by decomposition. In most herbivorous animals, on the contrary, the urine is alkaline and turbid. The difference depends, not on any peculiarity in the mode of secretion, but on the differences in the food on which the two classes subsist; for when carnivorous animals, such as dogs, are restricted to a vegetable diet, their urine becomes pale, turbid, and alkaline, like that of an herbivorous animal, but resumes its former acidity on the return to an animal diet; while the urine voided by herbivorous animals, *e. g.*, rabbits fed for some time exclusively upon animal substances, presents the acid reaction and other qualities of the urine of Carnivora, its ordinary alkalinity being restored only on the substitution of a vegetable for the animal diet (Bernard, xviii. 1846). Human urine is not usually rendered alkaline by vegetable diet, but it becomes so after the free use of alkaline medicines, or of the alkaline salts with carbonic or vegetable acids; for these latter are changed into alkaline carbonates previous to elimination by the kidneys. Except in these cases it is very rarely alkaline, unless ammonia has been developed in it by decomposition commencing before it is evacuated from the bladder.

The average *specific gravity* of the human urine is stated by Dr.

... length of time whic
meal, and by several other accidental cir
of these causes of difference in the comp
to the secretion being described under
sanguinis, *urina potûs*, and *urina cibi*.
signifies the urine, or that part of it, w
blood at times in which neither food no
taken, and is applied especially to the ur
the morning before breakfast. The *urina*
secreted shortly after the introduction of a
of fluid into the body: and the *urina ci*
during the period immediately succeedin
The latter kind contains a larger quantit
either of the others; the former, being lar
possesses a comparatively low specific gravity
the morning-urine is the best calculated for
sents the simple secretion unmixed with th
drink; if it be not used, the whole of the
period of twenty-four hours should be taken
the various circumstances above mentioned,
the urine may, consistently with health, ran
of the usual average. The average healthy
from 1015 in the winter to 1025 in the summ
Am. Ed.), and variations of diet and exercis
difference. In disease, the variation may
descending, in albuminuria, to 1004, and fr
diabetes, when the urine is loaded with sug
1060 (Watson, xlviii. p. 870).

The whole

will give a mean of 35 ounces as the average amount of the urinary secretion by an adult healthy man.

Chemical Composition of the Urine.

The urine consists of water, holding in solution certain animal and saline matters as its ordinary constituents, and occasionally various matters taken in the stomach as food—salts, coloring matters, and the like. The quantities of the several natural and constant ingredients of the urine are stated somewhat differently by the different chemists who have analyzed it; but many of the differences are not important, and the well-known accuracy of the several chemists renders it almost immaterial which of the analyses is adopted. The analysis by A. Becquerel (l. p. 7) being adopted by Dr. Prout (xxi. p. 404, Am. Ed.), and by Dr. Golding Bird (li. p. 59, Am. Ed.), will be here employed. The older analysis by Berzelius (xxiv. p. 342), adopted by Müller (xxxii. p. 460, Am. Ed.), includes all the principal solid constituents of the urine, and probably states correctly the proportions that they bear to one another; but, as pointed out by Dr. Prout, it is probable that Berzelius examined urine of very high specific gravity, and has in consequence overstated the quantity of solid ingredients; for he sets them down at more than double the amount found to exist by more recent analysts. If the mean specific gravity of human urine be taken at 1020, and the average quantity passed in twenty-four hours be estimated at thirty-five ounces, it will be found, according to the analysis of M. Becquerel, that 1000 parts of urine contain 33 parts of solid matter dissolved in 967 parts of water. Its more exact composition is as follows:—

Water			967.
Urea			14.230
Uric acid			.468
Coloring matter, and animal extractive matter		inseparable from each other	10.167
Salts	Sulphates	Soda, Potash	8.135
	Bi-phosphates	Lime, Soda, Magnesia, Ammonia	
	Chlorides	Sodium, Potassium	
	Hippurate of soda		
	Fluate of potash		
	Silica		traces.
			1000.000

From these proportions, however, most of the constituents are,

even in health, liable to variations. Especially, the *water* is so. Its variations in different seasons, and according to the quantity of drink and exercise are already mentioned. It is also liable to be influenced by the condition of the nervous system, being sometimes greatly increased in hysteria, and some other nervous affections; and at other times diminished. In some diseases it is enormously increased; and its increase may be either attended with an augmented quantity of solid matter, as in diabetes, or may be nearly the sole change, as in the ...ed diabetes insipidus. In other diseases, *e. g.*, the ...f albuminuria, the quantity may be considerably din... ...rile condition almost always diminishes the quantity of ... ...a like diminution is caused by any affection which dr... ... quantity of fluid from the body through any other ...hat of the kidneys, *e. g.*, the bowels and the s...

Urea.—Urea is t... ...constituent of the urine, forming nearly one-half of the whole quantity of solid matter. It is also the most important ingredient, since it is the chief substance by which the nitrogen of decomposed tissues and superfluous food is excreted from the body. For its removal the secretion of urine seems especially provided, and by its retention in the blood the most pernicious effects are produced.

Urea, like the other solid constituents of the urine, exists in a state of solution. But it may be procured in the solid state, and then appears in the form of delicate silvery acicular crystals, which, under the microscope, appear as four-sided prisms. It is obtained in this state by evaporating urine carefully to the consistence of honey, acting on the inspissated mass with four parts of alcohol, then evaporating the alcoholic solution, and purifying the residue by repeated solution in water or alcohol, and finally allowing it to crystallize. It readily combines with an acid, like a weak base; and may thus be conveniently procured in the form of a nitrate, by adding about half a drachm of pure nitric acid to double that quantity of urine in a watch-glass. The crystals of nitrate of urea are formed more rapidly if the urine have been previously concentrated by evaporation.

Urea is colorless when pure; when impure, yellow or brown; without smell, and of a cooling, nitre-like taste; has neither an acid nor an alkaline reaction, and deliquesces in a moist and warm atmosphere. At 59° F. it requires for its solution less than its weight of water; it is dissolved in all proportions by boiling water: but it requires five times its weight of cold alcohol for its solution. At 248° F. it melts without undergoing decomposition; at a still higher temperature ebullition takes place, and carbonate of ammonia sublimes; the melting mass gradually acquires a pulpy consistence,

and, if the heat is carefully regulated, leaves a gray-white powder, cyanic acid.

Urea is identical in composition with cyanate of ammonia, its ultimate analysis yielding 2 atoms of carbon, 2 of nitrogen, 2 of oxygen, and 4 of hydrogen, which is the composition of hydrated cyanate of ammonia (cyanic acid=C_2NO; water=HO; ammonia =NH_3). This cyanate of ammonia, or artificial urea, as discovered by Wöhler, may be formed by the mutual action of ammonia, cyanic acid, and water; or by decomposing cyanate of silver with hydrochlorate of ammonia, or cyanate of lead with a solution of ammonia (liii. xxvii. 196). The action of heat upon urea in evolving carbonate of ammonia, and leaving cyanic acid, is thus explained. A similar decomposition of the urea with development of carbonate of ammonia ensues spontaneously when urine is kept for some days after being voided, and explains the ammoniacal odor then evolved. It is probable that this spontaneous decomposition is accelerated by the mucus and other animal matters in the urine, which, by becoming putrid, act the part of a ferment and excite a change of composition in the surrounding compounds. It is chiefly thus that the urea is sometimes decomposed before it leaves the bladder, when the mucous membrane is diseased, and the mucus secreted by it is both more abundant, and, probably, more prone than usual to become putrid (Dumas, lii. p. 39). The same occurs also in some affections of the nervous system, particularly in paraplegia.

Assuming 35 ounces of urine to be passed in twenty-four hours, the total amount of urea excreted within the same period, at the rate of fourteen parts and a quarter in every 1000 parts of urine, will be 227 grains, or nearly half an ounce. The amount of this substance excreted is, however, like that of the urine itself, subject to considerable variation. It is materially influenced by diet, being greater when animal food is exclusively used, less when the diet is mixed, and least of all with a vegetable diet (Lehmann, lxxxii. p. 416). As a rule, men excrete a larger quantity than women, and persons in the middle periods of life a larger quantity than infants or old people (Lecanu, lvi. t. 25, p. 261). The quantity of urea does not necessarily increase and decrease with that of the urine, though on the whole it would seem that whenever the amount of urine is much augmented, the quantity of urea also is usually increased (Becquerel, l.). In various diseases, as albuminuria, the quantity is reduced considerably below the healthy standard, while in other affections it is raised above it.

The urea appears to be derived from two different sources. That it is derived in part from the unassimilated elements of nitrogeneous food, circulating with the blood, is shown in the increase which ensues on substituting an animal or highly nitrogenous, for a vegetable diet. And that it is in larger part derived from the disin-

tegration of the azotized animal tissues, is shown by the fact, that it continues to be excreted, though in smaller quantity than usual, when all nitrogenous substances are strictly excluded from the food, as when the diet consists for several days of sugar, starch, gum, oil, and similar non-azotized vegetable substances (Lehmann, lxxxii. p. 417). It is excreted also even although no food at all is taken for a considerable time; thus it is found in the urine of reptiles which have fasted for [illegible] and in the urine of a madman who had fasted eighteen d[illegible] ge found both urea and all the components of healt[illegible] ii. p. 272). According to Dr. Prout (xxi. p. 411, [illegible] the urea is derived chiefly from the gelatinous tissu[illegible] g to Liebig (xi. p. 137), all the nitrogenous tissues f[illegible] a s[illegible] e of it by their decomposition; and that the muscles [illegible] is [illegible]rly proved by the close relation between urea and t[illegible] reatine and kreatinine which both they and urine contain, and [illegible] the increased excretion of urine after active exercise.

Urea exists ready-formed in the blood, and is simply abstracted therefrom by the kidney. It may be detected in small quantity in the blood (ix. 1848), and in some other parts of the body, *e. g.*, the humors of the eye (Millon, xviii. 1843), even while the functions of the kidneys are unimpaired; but when from any cause, especially extensive disease or extirpation of the kidneys, the separation of urine is imperfect, the urea is found largely in the blood and most other fluids of the body.

Uric Acid.—This, which is another nitrogenous animal substance, and was formerly termed lithic acid on account of its existence in many forms of urinary calculi, is rarely absent from the urine of man or animals, though in the feline tribe it seems to be sometimes entirely replaced by urea (G. Bird, lxxi. vol. xli. p. 1106). Its proportionate quantity varies considerably in different animals. In man, and Mammalia generally, especially the Herbivora, it is comparatively small, not exceeding, in the human subject, one part in 2000 parts of urine. In the whole tribe of birds and of serpents, on the other hand, the quantity is very large, greatly exceeding that of the urea. In the urine of graminivorous birds, indeed, urea is rarely if ever found, its place being entirely supplied by uric acid. The quantity of uric acid, like that of urea, in human urine is increased by the use of animal food, and decreased by the use of food free from nitrogen, or by an exclusively vegetable diet. In most febrile diseases, and in plethora, it is formed in unnaturally large quantities, and in gout it is deposited in, and in the tissues around, joints, in the form of urate of soda, of which the so-called chalk-stones of this disease are principally composed.

The condition in which uric acid exists in solution in the urine, has formed the subject of much discussion, because of its difficult

solubility in water. Dr. Prout found that it required 10,000 times its weight of water, at the temperature of 60° F. for solution; whereas in urine, one part of it is retained in solution by only 2000 parts of water. He was led to believe that uric acid does not exist in the free state in urine, but is combined with ammonia in the form of the more soluble salt of urate of ammonia. This view is supported by the fact that urine, when evaporated, deposits not crystals of uric acid, as would probably be the case if this acid existed in its free state, but urate of ammonia. It is supported also by the facts, that the addition of an acid to urine causes the deposition of crystals of uric acid, and that the uric acid in the excrement of birds and serpents is not in the free state, but is combined with ammonia. It may, therefore, be considered highly probable that the principal part at least of the uric acid exists in the urine in the form of urate of ammonia; and Dr. Bence Jones has shown that the solubility of this salt is increased by the presence of chloride of sodium, of which a proportion is present in the urine (lxxi. Dec. 1843).

Liebig (xxx. June, 1844), however, maintains that the uric acid exists as urate of soda, produced, he supposes, by the uric acid, as soon as it is formed, combining with part of the base of the alkaline phosphate of soda of the blood. Hippuric acid, which exists in human urine also, he believes, acts upon the alkaline phosphate in the same way, and increases still more the quantity of acid phosphate, on the presence of which it is probable that a part of the natural acidity of the urine depends. It is scarcely possible to say whether the union of uric acid with the bases soda and ammonia, takes place in the blood, or in the act of secretion in the kidney; the latter is the more probable opinion, but the quantity of either uric acid or urates in the blood, is probably too small to allow of this question being solved.

According to Dr. Prout, the source of uric acid is in the disintegrated elements of albuminous tissues: while by Liebig it is assumed that uric acid is the first-formed product of the decay of all azotized tissues, and that if a due supply of oxygen is afforded, it is resolved into urea and carbonic acid. The fact, however, that in birds, whose rapid respiration and circulation insures a large supply of oxygen, the uric acid is excreted in the form of urate of ammonia, and is rarely converted into urea, is quite opposed to such a view. The relation which uric acid and urea bear to each other is therefore still obscure. The fact that they often exist together in the same urine, seems to make it probable that they have different origins or different offices to perform: but the entire replacement of either by the other, as of urea by uric acid in the urine of birds, serpents, and many insects, and of uric acid by urea

in the urine of the feline tribe of Mammalia, shows that each alone may discharge all the important functions of the two.

Owing to its existing in combination in healthy urine, uric acid, for examination, must generally be precipitated from its bases, by a stronger acid. Frequently, however, when excreted in excess, it is deposited in a crystalline form, mixed with large quantities of urate of ammonia. In such cases it may be procured for microscopic examination by gent portion of the urine containing the sediment: this c urate of ammonia, while the comparatively insoluble c acid subside to the bottom. In larger quantity, this obtained from the urine of birds or serpents, whi ost exclusively of urate of ammonia. The thick secretion of these animals is to be dried, dissolved i ltered, and then decomposed with nitric or hydrochl

The most common fo ic acid is deposited in urine is that of a brownish or yellowish powdery substance, consisting of granules of urate of ammonia. When deposited in crystals, it is most frequently in rhombic or diamond-shaped laminæ, not unlike scales of epithelium, their resemblance to which is often further increased by the existence of internal markings, which look like nuclei. The laminæ are sometimes of considerable thickness, and when lying on their sides they often appear like flattened cylinders; but their true form is made manifest as they roll over. Occasionally the rhombic form of the crystals is replaced by the square. Various other shapes are also occasionally presented, and will be found described in works on the subject (see especially Prout, xxi.; G. Bird, li.; Simon, lxxxii.; Griffith, cii.). When deposited from urine, the crystals are generally more or less deeply colored, by being combined with the coloring principles of the urine.

Uric acid is insoluble in ether and alcohol. It contains about 31 per cent. of nitrogen; its analysis yielding, according to Dr. Prout, nitrogen 31.12, carbon, 39.87, hydrogen 2.22, oxygen 26.77. Its formula is $C_{10}H_4N_4O_6$.

Hippuric acid has long been known to exist in the urine of herbivorous animals in combination with soda. Liebig has lately shown that it also exists naturally in the urine of man, in quantity equal to the uric acid (xxx. June, 1844); but, according to Dr. G. Bird, its quantity is not more than one-third of the uric acid. It is a nitrogenous compound, and contains as much as 63 per cent. of carbon; 100 parts, according to Liebig, consisting of C 63.032, H 5.000, N 7.337, O 24.631. It is closely allied to benzoic acid, and this substance, when introduced into the system, is excreted by the kidneys as hippuric acid (Ure, xli. vol. xxiv.). Its source is in some parts of vegetable diet, though man has no hippuric acid

his food, nor, commonly, any benzoic acid that might be converted into it.

The nature and composition of the *coloring matter* of urine is involved in considerable obscurity. It is usually supposed that there are two distinct kinds, a yellow and a red, by the varying proportions of which the different tints of urine are produced. (See on the subject G. Bird, li. p. 85, 2d Am. Ed.; Heller, ix. 1846–7; Simon, lxxxii.; and for the best and most recent account Scherer, Bd. 57, p. 180, or for an abstract of the paper there given, lix. 1846, p. 130.)

The *mucus* in the urine consists principally of the epithelial debris of the mucous surface of the urinary passages. Particles of epithelium, in greater or less abundance, may be detected in most samples of urine, especially if it has remained at rest for some time, and the lower strata are then examined. As urine cools, the mucus is sometimes seen suspended in it as a delicate opaque cloud, but generally it falls. In inflammatory affections of the urinary passages, especially of the bladder, mucus in large quantities is poured forth, and speedily undergoes decomposition. The presence of the decomposing mucus excites (as already stated) chemical changes in the urea, whereby ammonia, or carbonate of ammonia, is formed, which combining with the excess of acid in the super-phosphates in the urine, produces insoluble neutral or alkaline phosphates of lime and magnesia, and phosphate of ammonia and magnesia. These, mixing with the mucus, constitute the peculiar white, viscid, mortar-like substance which collects upon the mucous surface of the bladder, and is often passed with the urine, forming a thick tenacious sediment.

Besides mucus and coloring matter, urine contains a considerable quantity of animal matter, usually described under the obscure name of *animal extractive*. The investigations of Liebig (liv.), Heintz (lix. 1847, p. 105), and others, have shown that some of this ill-defined substance consists of *kreatine* and *kreatinine*, two substances derived from the metamorphosis of muscular tissues. These substances appear to be intermediate between the proper elements of the muscles, and perhaps of other azotized tissues, and urea: the first products of the disintegrating tissues probably consisting, not of urea, but of kreatine and kreatinine, which subsequently are partly resolved into urea, partly discharged, without change, in the urine. Scherer's analysis shows, also, that much of the substance classed as extractive matter of the urine, is a peculiar coloring matter, probably derived from the hæmatine of the blood.

Salts.—The saline substances in urine, constitute about one-fourth of the solid ingredients. They consist of the various saline

[illegible], it is probable that the sulphates in the urine contain, as soon as or in the act of secretion of urine, is con potash, which are in excess in the bloo The sulphur of which the acid is formed, the decomposing nitrogeneous tissues, the are resolved into urea and uric acid. through the lungs, and the heat generated the sulphur, is one of the subordinate mea temperature is maintained.

Besides the sulphur in these salts, some urine, uncombined with oxygen; for after been removed from urine, sulphuric acid ma and burning it with nitre. Mr. Ronalds b to five grains of sulphur are thus daily excre combination in which it exists is uncertain: compound analogous to cystine or cystic oxi much as 25 per cent. of sulphur.

The phosphates are more numerous, thou the sulphates. From 1-4th to 1-18th part of with alkaline bases; from 3-4ths to 17-18t (Bence Jones, xliii. 1845). In blood, saliv fluids of the body, phosphates exist in the fo bly tribasic salts. In the urine, they are bi-phosphates of soda, ammonia, lime, and m acid being, according to Liebig (xxx. June, propriation of the alkali with which the p blood is combined, by the several [illegible] discharged [illegible]

The decomposition of other tissues, also, but especially of the brain and nerve-substance, furnishes large supplies of phosphorus to the urine, which phosphorus is supposed, like the sulphur, to be united with oxygen, and then combined with bases. According to Becquerel, 1000 parts of urine contain on an average .373 of phosphoric acid in the state of combination; so that a person in health will pass about 5.72 grains in twenty-four hours. This quantity is, however, liable to considerable variation. Any undue exercise of the mind, and all circumstances producing nervous exhaustion, increase it. The earthy phosphates are more abundant after meals, whether on animal or vegetable food, and are diminished after long fasting. The alkaline phosphates are increased after animal food, diminished after vegetable food. Exercise increases the alkaline, but not the earthy phosphates (Bence Jones). Phosphorus uncombined with oxygen appears, like sulphur, to be excreted in the urine (Ronalds, l. c.), and it is said that the quantity is sometimes so large as to render objects dipped in the urine luminous in the dark (liii. Feb. 1814).

The *chlorides* occur as chlorides of potassium and sodium. As they exist largely in food, and in most of the animal fluids, their occurrence in the urine is easily understood. Occasionally, the urine contains *fluate of potash*, and a small quantity of *silica*; but neither of these appears to be a constant constituent.[1]

CHAPTER XV.

THE NERVOUS SYSTEM.

THE general nature of the functions of the nervous system, its connection with the mind on the one hand, and the contractile and sensitive parts on the other, and its influence on the functions of organic life, have been already referred to (pp. 40–42). The following pages will be devoted to a fuller exposition of these subjects.

The nervous system consists of two portions or constituent systems, the *cerebro-spinal*, and the *sympathetic* or *ganglionic*, each of which (though they have many things in common) possesses

[1] In addition to the various works already quoted, see, for further details on the Chemistry of the Urine, Dr. Garrod's lectures, in the Lancet for 1848; Dr. Golding Bird's lectures in the forty-second volume of the Medical Gazette; Dr. Day's several reports in Ranking's Abstract; and the works of Dr. Griffith (cii.) and Dr. Bence Jones (cxcvii.).

and the mental acts connected with sensi

The *sympathetic* or *ganglionic* portion which Bichat named the nervous system essentially of a chain of ganglia connected extends from the cranium to the pelvis, al tebral column, and from which nerves wit viscera in the thoracic, abdominal, and pel tribution, as well as by its peculiar mode c less immediately connected with the mind, as receiving the impulses of the will; it is than the cerebro-spinal system is with th life.

But the differences between these two syst their actions differ in degree and object more in the lower animals all the nervous function system corresponding with the cerebro-spin and among the Vertebrata many of the fu warm-blooded animals are controlled by th are in fish under the control of the pneumog

Elementary Structures of the Nerv

The organs of the nervous system, or s essentially of two kinds of structure, vesicu of which appear essential to the constructior nervous system. The vesicular structure i masses and mingled with the fibrous struct nal cord, and th

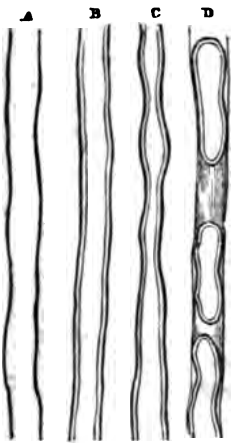
nervous force to them, or of transmitting to the nervous centres the impressions made by stimuli.

Along the nerve-fibres impressions or conditions of excitement are simply conducted: in the nervous centres they may be made to deviate from their direct course, and be variously diffused, reflected, or otherwise disposed of.

Nerves are constructed of minute fibres or tubules full of nervous matter, arranged in parallel or interlacing bundles, which bundles are connected by intervening fibro-cellular tissue, in which their principal blood-vessels ramify. A layer of the same, or of strong fibrous tissue, also surrounds the whole nerve, and forms a sheath or neurilemma for it. In most nerves, two kinds of fibres are mingled; those of one kind being most numerous in, and characteristic of, nerves of the cerebro-spinal system; those of the other, most numerous in nerves of the sympathetic system.

The fibres of the first kind appear to consist of tubules of a pellucid simple membrane, within which is contained the proper nerve-substance, consisting of a transparent oil-like, and apparently homogeneous material, which gives to each fibre the appearance of a fine glass-tube filled with a clear transparent fluid (Fig. 60, A). This simplicity of composition, is, however, only apparent in the fibres of a perfectly fresh nerve; for shortly after death they undergo changes which make it probable that their contents are composed of two different materials. The internal, or central part, occupying the axis of the tube, becomes grayish, while the outer, or cortical portion, becomes opaque and dimly granular or grumous, as if from a kind of coagulation. At the same time, the fine outline of the previously transparent cylindrical tube is exchanged for a dark double contour (Fig. 60, B), the outer line being formed by the sheath of the fibre, the inner by the margin of curdled or coagulated medullary substance. The granular material shortly collects into little masses, which distend portions of the tubular membrane, while the intermediate spaces collapse, giving

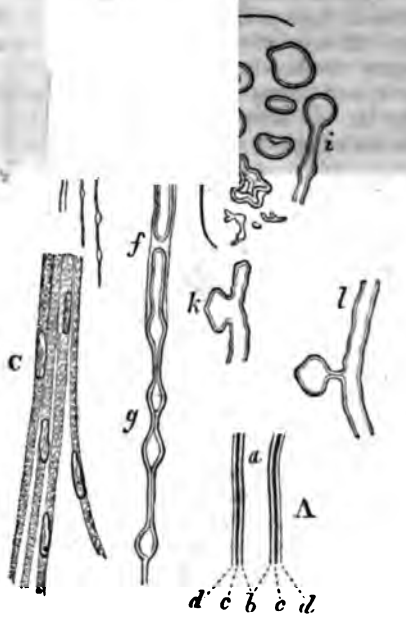
Fig. 60.



Primitive nerve-tubules. A. A perfectly fresh tubule with a single dark outline. B. A tubule or fibre with a double contour from commencing *post-mortem* change. C. The changes further advanced, producing a varicose or beaded appearance. D. A tubule or fibre, the central part of which, in consequence of still further changes, has accumulated in separate portions within the sheath. After Wagner (cxv.).

the fibres a varicose or beaded appearance (Fig. 60, c and d), instead of their previous cylindrical form.

The difference produced in the contents of the nerve-fibres when exposed to the same conditions, has, with other facts, led to the opinion that the central part of each nerve-fibre differs from the circumferential portion: and the former has been named by Rosenthal and Purkinje (xxxiv. 1840, p. 76), the *axis-cylinder*, by Remak (xxxviii. June, 1838) the *primitive band*. The outer



A. Diagram of tubular fibre of a spinal nerve: *a*. Axis-cylinder. *b*. Inner border of white substance. *c*, *c*. Outer border of white substance. *d*, *d*. Tubular membrane. B. Tubular fibres; *e*, in a natural state, showing the parts as in A. *f*. The white substance and axis-cylinder, interrupted by pressure while the tubular membrane remains. *g*. The same, with varicosities. *h*. Various appearances of the white substance, and axis-cylinder forced out of the tubular membrane by pressure. *i*. Broken end of a tubular fibre, with the white substance closed over it. *k*. Lateral bulging of white substance and axis-cylinder from pressure. *l*. The same, more complete. *g'*. Varicose fibres of various sizes, from the cerebellum. C. Gelatinous fibres from the solar plexus, treated with acetic acid to exhibit their cell nuclei. B and C magnified 320 diameters.

portion is usually called the medullary or *white substance* of Schwann, being that to which the peculiar white aspect of cerebro-

rves is principally due. The whole contents of the nerve-
ppear to be extremely soft, for when subjected to pressure
lily pass from one part of the tubular sheath to another,
n cause a bulging at the side of the membrane. They
ily escape on pressure from the extremities of the tubule,
rm of a grumous or granular material. (Fig. 61.)
ze of the nerve-fibres varies, and the same fibres do not
the same diameter through their whole length, being
ı their course within the trunks and branches of the nerves,
, the majority measure from 1-2000th to 1-3000th of an
liameter. As they approach the brain or spinal cord, and
y also in the tissues in which they are distributed, they
y become smaller. In the gray or vesicular substance of
in and spinal cord, they generally do not measure more
m 1-10,000th to 1-14,000th of an inch (cxiii. Heft. ii.).
ibres of the second kind, which constitute the principal part
trunk and branches of the sympathetic nerves, and are
l in various proportions in the cerebro-spinal nerves, differ
e preceding, chiefly in their fineness, being only about ½ or
ge in their course within the trunks and branches of the
in the absence of the double contour; in their contents
pparently uniform; and in their having, when in bundles,
rish-gray hue instead of the whiteness of the cerebro-spinal
These peculiarities make it probable that they differ from
:r nerve-fibres in not possessing the outer layer of white or
ry nerve-substance; and that their contents are composed
ely of the substance corresponding with the central portion,
cylinder of the larger fibres (Fig. 62). Yet since many
ores may be found which appear intermediate in character
, these two kinds, and since the large fibres, as they ap-
both their central and their peripheral ends, gradually
ı in size, and assume many of the other characters of the
es of the sympathetic system, it is not necessary to sup-
it there must be a material difference in the office or mode
n of the two kinds of fibres.[1]
y nerve-fibre in its course proceeds uninterruptedly from its
t a nervous centre to its destination, whether this be at the
y of the body, in another nervous centre, or in the same
hence it issued. In the whole of its course, also, however

[1] the best account of the structure of nerve-fibres, see xxv. 1842, in an analysis of the descriptions by Valentin, Henle, Remak, Purkinje, Krause, Ehrenberg, and other continental writers; also the more recent investigations, by Will, Hannover, Kölliker, and the subsequent reports; and the various reports in Canstatt's richt up to 1847; see also Dr. Todd and Mr. Bowman, in their pical Anatomy.

Roots of a dorsal spinal nerve, and its union with sympat
the spinal cord. *a*. Anterior root. *p*. Posterior root, with its g
p'. Posterior branch. *s*. Sympathetic. *c*. Its double junctio
the spinal nerve by a white and gray filament.

merely lie in apposition with each oth
where the fa

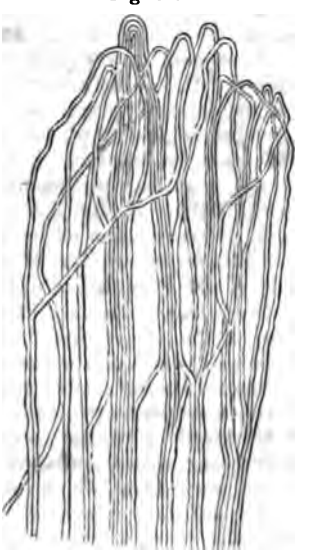
rain, spinal cord, or other nervous centre: so that, corresponding o the many millions of primitive fibres which are distributed to eripheral parts of the body, there are the same number of peri-heral points of the body, represented in the nervous centres.

At certain parts of their course nerves form *plexuses* in which hey anastomose with each other, and interchange fasciculi, as in he case of the brachial and lumbar plexuses. The object of such interchange of fibres is, probably, to give to each nerve passing off from the plexus a wider connection with the spinal cord than it would have if it proceeded to its destination without such communication with other nerves. Thus, since the brachial plexus is formed by the intermingling of fasciculi from the four last cervical, and the first dorsal nerves, it is possible that each trunk coming off from it may contain fibres derived from several parts of the cord intermediate between the roots of the fourth cervical and those of the first dorsal. By this means the parts supplied from the brachial plexus are enabled to have wider relations with the nervous centres, and more extensive sympathies.

The *terminations* of nerve-fibres are their modes of distribution and connection in the nervous centres, and in the parts which they supply: the former are called their *central*, the latter their *peripheral* terminations.

As they approach their final nd minutest distribution in the everal tissues, the small bundles f nerve-fibres commonly form deli-ate plexuses, the *terminal plexuses*. hese, then dividing or breaking p, give off the primitive fibres, hich appear to be disposed of in arious ways in different tissues. It exceedingly difficult to determine ow they terminate: but examples f each of the four following modes ave been observed. 1. In *loops*. n this (which can only conventionlly be called a mode of termination) ach fibre, after issuing from a ranch in a terminal plexus, runs ver the elementary structures of ie containing tissue, then turns ack, and joins the same or a neighoring branch, in which it probably ursues its way back to a nervous entre. This arrangement has been ound in the internal ear (Hannover,

Fig. 63.



Terminal nerves on the sac of the second molar tooth of the lower jaw in the sheep, showing the arrangement in loops. After Valentin.

cxix.), in the papillæ of the tongue (Todd and Bowman, xxxix. p. 440), in the tooth pulp (Valentin, xxxix. p. 221) (Fig. 63): it probably exists, also, in the tactile papillæ of the skin (Fig. 64), and,

Fig. 64.

Distribution of the ... section of the skin.

... the lip; as seen in a thin perpendicular

in a modified form, in striped muscular tissue. But in the latter, Wagner (cxv.) and Volkmann (cxxvi. p. 70) assert that each ultimate fibre breaks up into several branches, which spread out over the muscular fibres, and, according to Wagner, penetrate within the sarcolemma of each fibril. 2. In *plexuses*. Thus, nerve-fibres appear to terminate in certain serous membranes. According to Mr. Rainey (xli. vol. xxix. p. 85), the arachnoid membrane of the brain and spinal cord is traversed by innumerable delicate nerve-fibres, arranged in minute plexuses; and a similar mode of arrangement appears to be observed by the nerve-fibres in other serous membranes, *e. g.*, the peritoneum (Bourgery, xix. 1845, Pappenheim, xviii. 1845). 3. By *free ends*. It is not improbable that this mode of termination exists in several parts, as in the retina, and, possibly, in the papillæ of the skin; but it has been determined only in the *Pacinian corpuscles*.

These corpuscles are little elongated, oval bodies, situated on some of the cerebro-spinal and sympathetic nerves, especially the cutaneous nerves of the hands and feet (Figs. 65 and 66). They are named Pacinian, after their discoverer, Pacini.[1] Each corpuscle is attached by a narrow pedicle to the nerve on which it is situated; it is formed of several concentric layers of fine membrane, with intervening spaces containing fluid; through its pedicle passes a single nerve-fibre, which, after traversing the several concentric layers and their intermediate spaces, enters a central cavity, and gradually losing its dark border, and becoming smaller, terminates

[1] See, for a description of these bodies, an abstract of Henle and Kölliker's essay on them (xxv. 1843–4, p. 46), and Mr. Bowman, in the Cyclopædia of Anatomy and Physiology.

at or near the distal end of the cavity in a knob-like enlargement, or by bifurcating. The enlargement commonly found at the end

Fig. 66.

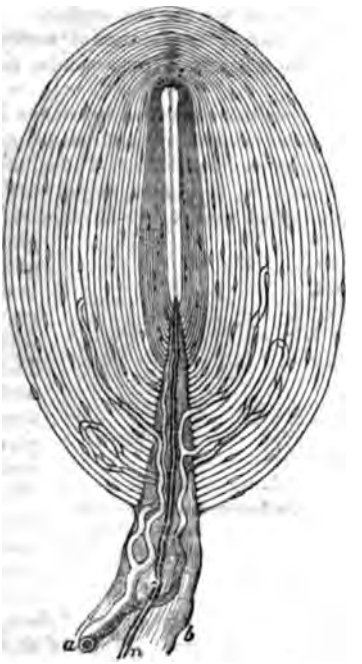


Fig. 65.

A B

Fig. 65. Extremities of a nerve of the finger with Pacinian corpuscles attached. A. Nerve from the finger, natural size: showing the Pacinian corpuscles. B. Ditto, magnified two diameters, showing their different size and shape.

Fig. 66. Pacinian corpuscle from the mesentery of a cat; intended to show the general construction of these bodies. The stalk and body, the outer and inner system of capsules with the central cavity are seen. *a*. Arterial twig, ending in capillaries, which form loops in some of the inter-capsular spaces, and one penetrates to the central capsule. *b*. The fibrous tissue of the stalk, prolonged from the neurilemma. *n*. Nerve tube advancing to the central capsule, there losing its white substance, and stretching along the axis to the opposite end, where it is fixed by a tubercular enlargement.

of the fibre, is said by Pacini (cxx. 1845, p. 208) to resemble a ganglion-corpuscle; but this observation has not been confirmed. 4. Another mode of termination of nerve-fibres has been described by Wagner (cxv.) as occurring in the electric organ of the ray. A large nerve-fibre suddenly breaks up into from twelve to fifteen branches, each of which again divides into two secondary branches.

Some secondary branches anastomose and form a network; while ...s divide again dichotomously, each of these branches again anastomosing and subdividing, until a very fine network is formed, from which branches pass off, and seem to be lost in the substance of the electric organs.

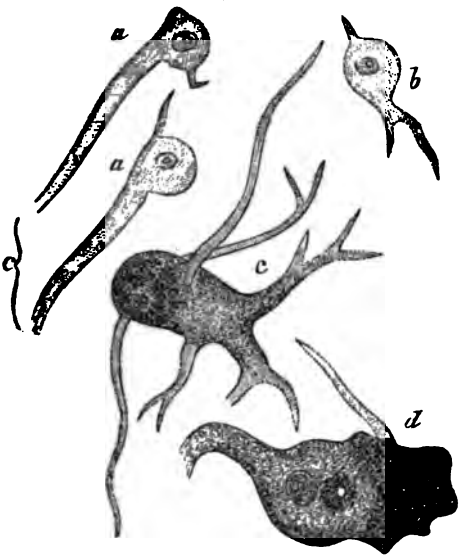
The *central* termination of nerve-fibres can be better considered after the account of the vesicular nerve-substance.

The *vesicul*... composed, as its name implies, of vesicles or ...monly called nerve-corpuscles, or ganglion ... found only in the nervous centres, *i. e* ... and the various ganglia; they are ming... ...nbedded in a dimly-shaded or ...lar substance; they give to the ...lia, and to certain parts of the ... and spinal cord, the peculiar grayish or reddish-gray aspect by which these parts are characterized. They are large nucleated cells, filled with a finely granular material, some of which is often dark like pigment: the nucleus, which is vesicular, contains a nucleolus (Fig. 67). Besides varying much in shape, partly in consequence of mutual pressure, they present such other varieties as make it probable either that there are two different kinds, or that, in the stages of their development, they pass through very different forms. Some of them are small, generally spherical or ovoid, and have a regular uninterrupted outline (Fig. 67). These *simple* nerve-corpuscles are most numerous in the sympathetic ganglia. Others, which are called *caudate* or *stellate nerve-corpuscles* (Fig. 68), are larger, and have one, two, or more long processes issuing from them, which processes often divide and subdivide, and appear tubular, and filled with the same kind of granular material as is contained within the corpuscle. Of these processes some appear to taper to a point, and terminate at a greater or less distance from the corpuscle; others may be traced until each of them, gradually losing its granular appearance, becomes continuous with, and acquires all the characters of, a perfect nerve-fibre (Fig. 69).

Nerve-corpuscles from a ganglion; after Valentin. In one, a second nucleus is visible. The nucleus of several contains one or two nucleoli.

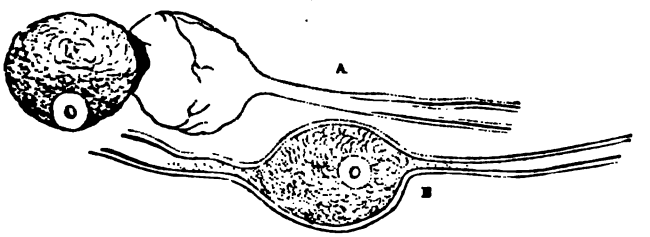
It is probable that the majority of nerve-fibres, when they enter a nervous centre, terminate, or, perhaps, more correctly, originate in this mode of connection with nerve-corpuscles. As they enter, the fibres gradually become finer: some, possibly, form simple loops; but the majority enter into connection with nerve-corpuscles

Fig. 68.



Ganglion globules, with their processes, nuclei, and nucleoli: *a,a.* From the deeper part of the gray matter of the convolutions of the cerebellum. The larger processes are directed towards the surface of the organ. *b.* Another from the cerebellum. *c, d.* Others from the post-horn of gray matter of the dorsal region of the cord. These contain pigment, which surrounds the nucleus in *c.* In all the specimens the processes are more or less broken. Magnified 200 diameters.

Fig. 69.



Connection between nerve-fibres and nerve-corpuscles; from the roots of a spinal nerve of the ray. After Wagner (CXV.). A. A nerve-corpuscle, escaped by pressure from the capsule formed around it by the dilated sheath of the nerve-tubule: it shows also the gradual disappearance of the outer portion of the substance of the nerve as it comes into relation with the corpuscles. B. A nerve-corpuscle inclosed within a dilated portion of the sheath of a nerve: part of the granular material of the corpuscle is continuous with the central substance of the nerve in the course of which it is inserted.

prolongation of the granular substa
thus appears to be inserted or received
fibre, extends for some distance along ea
taking the place of part of the proper sul

Among the many questions yet to be d
the connection of nerve-fibres with the c
centres, the principal are whether, in each
arise from corpuscles, or whether the corpu
inserted in the course of fibres that have sc
mination. In several instances, more fibr
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supposed to arise from the ganglion-corpusc
be determined whether this relation to gang
mon to all kinds of nerve-fibres or limite
functions. It does not belong exclusively t
spinal or the sympathetic nerves, for it has b
cord as well as in the sympathetic ganglia.
nerve-fibres, also, have been seen to issue fro
Wagner and Bidder mention having several t
of both kinds arising from the same corpusc
ion that sensitive fibres alone are brought into
with nerve-corpuscles (xv. Bd. iii. p. 455, an
dence for believing that the motor fibres have
is insufficient.

Functions of Nerve-Fibre

The office of the nerves, as simple conve
nervous impressions, is of
ment to the

from the brain and other nervous centres to the parts to which the nerves are distributed; and these impressions seem to be of at least two kinds, those, namely, which excite muscular contractions, and those which influence the secretion, nutrition, and other organic functions of a part.

For this twofold office of the nerves two distinct sets of nerve-fibres are provided, in both the cerebro-spinal and sympathetic systems. Those which convey impressions from the periphery to the centre are classed together as *centripetal* or *afferent* nerves, or, when speaking exclusively of cerebro-spinal nerves, *nerves of sensation*, or *sensitive nerves*. Those fibres, on the other hand, which are employed to transmit central impulses to the muscles are classed as *centrifugal*, *efferent*, or *motor* nerves, or *nerves of motion*. The nervous influence by which secretion and nutrition are controlled seems to be conveyed (as already stated, pp. 234–252) along both sensitive and the centrifugal sympathetic nerves.

With this difference in the functions of nerves, there is no apparent difference in the structure of the nerve-fibres by which it might be explained. Among the cerebro-spinal nerves, the fibres of the olfactory, optic, and auditory nerves are finer than those of the nerves of common sensation, and more like the fibres in the brain: but with these exceptions no centripetal fibres can be distinguished in their microscopic or general characters from those of motor nerves. Neither can the difference in functions be due to the kind of tissue to which a nerve is distributed, for although the nerves supplying muscles are principally motor, yet the muscular tissue contains sensitive fibres, also, for pain is felt when it is injured, and, as will be hereafter shown, much of the exactness and precision of muscular action is determined by the power which the muscular tissue has of communicating to the mind the sensation of its own contraction, and of the effects produced by it.

Nerve-fibres appear to possess no power of generating force in themselves, or of originating impulses to action: for the manifestation of their peculiar endowments they require to be stimulated. They possess a certain property of conducting impressions, a property which has been named excitability; but this is never manifested till some *stimulus* is applied (see pp. 41, 42). Under ordinary circumstances nerves of sensation are stimulated by external objects acting upon their extremities; and the nerves of motion by the will, or by some force generated in the nervous centres. But almost all things that can disturb the nerves from their passive state act as stimuli, and agents the most dissimilar produce the same kind, though not the same degree of effect, because that on which they act possesses but one kind of excitable force. Thus all stimuli, as well the internal organic as the inorganic—the chemical, mechanical, and electric—when applied to parts endowed with sen-

sation, or to sensitive nerves (the connection of the latter with the brain and spinal cord being uninjured), produce sensations; and when applied to the nerves of muscles excite contractions. Muscular contraction is produced as well when the motor nerve is still in connection with the brain, as when its communication with the nervous centres is cut off by dividing it; nerves, therefore, have by virtue of their excitability the property of exciting contractions in muscles to which th.. and the part of the divided motor nerve which is the muscle, will still retain this power, however n rtail it; but irritation of the other portion, which i rith the brain, never excites contractions of the

Mechanical irrit nt as to injure the texture of the primitive n he centripetal nerves of their power of produci. ritation is again applied at a point more distan.. an the injured spot; and in the same way, no irritation of a motor nerve will excite contraction of the muscle to which it is distributed, if the nerve has been compressed and bruised between the point of irritation and the muscle; the effect of such an injury being the same as that of division.

The action of nerves is also excited by *temperature*. Thus, when heat is applied to the nerve going to a muscle, or to the muscle itself, contractions are produced. These contractions are very violent when the flame of a candle is applied to the nerve, while less elevated degrees of heat—for example, that of a piece of iron merely warmed—do not irritate sufficiently to excite action of the muscles. The application of cold has the same effect as heat. The effect of the local action of excessive or long-continued cold or heat on the nerves, is the same as that of destructive mechanical irritation. The sensitive and motor power in the part is destroyed, but the other parts of the nerve retain their excitability; and, after the extremity of a divided nerve going to a muscle has been burnt, contractions of the muscle may be excited by irritating the nerve below the burnt part.

Chemical stimuli excite the action of both sensitive and motor nerves as mechanical irritants do; provided their effect is not so strong as to destroy the structure of the nerve to which they are applied. A like manifestation of nervous power is produced by *electricity* and by *magnetism*.

Some of these laws regulating the excitability of nerves and their power of manifesting their functions, require further notice, with several others which have not yet been alluded to. Certain of the laws and conditions of actions relate to nerves both of sensation and of motion, being dependent on properties common to all nerve-

bres; while of others, some are peculiar to nerves of motion, some o nerves of sensation.

It is a law of action in all nerve-fibres, and corresponds with the ontinuity and simplicity of their course, that an impression made n any fibre is simply and uninterruptedly transmitted along it, ithout being imparted or diffused to any of the fibres lying near t. In other words, all nerve-fibres are mere *conductors* of impresions. Their adaptation to this purpose is, perhaps, due to the ontents of each fibre being completely isolated from those of adjaent fibres by the membrane or sheath in which each is inclosed, nd which acts, it may be supposed, just as silk or other non-conuctors of electricity, when covering a wire, prevent the electric ondition of the wire from being conducted into the surrounding edium.

Nervous force travels along nerve-fibres with an immeasurable elocity. A certain period of time probably does elapse in the ransit of an impression from one end of a fibre to the other; but s length is inappreciable, and will probably never be ascertained, hile we have not the opportunity of tracing the passage through istances as vast as those through which the passage of light is alculated. (See, however, Helmholtz, lxxi. vol. x. n. s. p. 472). t has been supposed, indeed, that the velocity is less in some perons than in others; chiefly, because the impression of an object n the retina is sometimes perceived rather later by one person an by another—the difference amounting to one-third, or one-alf, or even a whole second. The cases in which this difference as been chiefly observed, are those in which the two senses of ght and hearing, are simultaneously engaged in noting the exact oment at which a star passes before the thread crossing the field of telescope. While the constant motion of the star across the field followed with the eye, the ear notes each stroke of the pendum-clock which stands near, marking the seconds. Now, it frequently happens, when two persons are thus engaged in making e same observation, that one of them notes the transit of the ar later than the other; as if either the velocity with which the mpression of the star passes along the optic nerve were less in one an in the other: or, as if one nerve conveyed impressions more pidly than another, so that the one person would see before he ears, the other hear before seeing. But, a more probable explanaon is, that both impressions are conveyed with the same immeaurable velocity, but the mind does not at the same instant take ognizance of both—for the mind does not readily perceive with qual distinctness two different simultaneous impressions, but rather, hen several impressions are made on the nerves at the same time, akes cognizance of only one at a time, and perceives the rest in uccession. When, therefore, both hearing and sight are directed

...produce movements in contrac
can transmit none but such as may pr
propagated to the brain. Moreover, the
sense, as the optic or auditory, can conv
may produce a peculiar sensation, *e. g.*
While the rays of light, and the sonor
are without influence on the nerves of co
stimuli, which may produce pain when a
when applied to these nerves of special s
tions of light, or sound, or taste, according

Of the laws of action, peculiar to ner
motion respectively, many can be ascertain
on the roots of the nerves. For, it is only
nerves of sensation and of motion are dis
shortly after their departure from the nervo
together, so that nearly all nerves, except
senses, consist of both sensitive and motor fi
termed mixed nerves.

Among the laws of action of *nerves of*
these nerves appear able to convey impressio
in which they are distributed, towards the
which they arise, or to which they tend. T
nerve is divided, and irritation is applied to
mal portion, *i. e.*, of the portion still conne
centre, sensation is perceived, or a reflex act
the end of the distal portion of the divi...
effect appears. The ...
not to ...

ere applied to the parts supplied by the branches of the nerve. hen the whole trunk of the nerve is irritated, the sensation is lt at all the parts which receive branches from it; but, when ly individual portions of the trunk are irritated, the sensation perceived at those parts only which are supplied by the several ortions. Thus, if we compress the ulnar nerve where it lies at e inner side of the elbow-joint, behind the internal condyle, we are the sensation of "pins and needles," or of a shock, in the parts which its fibres are distributed; namely, in the palm and back f the hand, and in the fifth and ulnar half of the fourth finger. When stronger pressure is made, the sensations are felt in the fore-rm also; and, if the mode and direction of the pressure be varied, he sensation is felt by turns in the fourth finger, in the fifth, in he palm of the hand, or in the back of the hand, according as lifferent fibres or fasciculi of fibres are more pressed upon than others.

It is in accordance with this law, that when parts are deprived of sensibility by compression or division of the nerve supplying them, irritation of the portion of the nerve connected with the brain still excites sensations which are felt as if derived from the parts to which the peripheral extremities of the nerve-fibres are distributed. Thus, there are cases of paralysis in which the limbs are totally insensible to external stimuli, yet are the seat of most violent pain, resulting apparently from irritation of the sound part of the trunk of the nerve still in connection with the brain, or from irritation of those parts of the nervous centre from which the sensitive erve or nerves supplying the paralyzed limbs originate.

An illustration of the same law is also afforded by the cases in hich division of a nerve for the cure of neuralgic pain is useless, id in which the pain continues or returns, though portions of the erve be removed. In such cases, the disease is probably seated arer the nervous centre than the part at which the division of e nerve is made, or it may be in the nervous centre itself. When e cause of the neuralgia is seated in the trunk of the nerve—for ample, of the facial or infra-orbital nerve—division of the branches n be of no service; for the stump remaining in connection th the brain, and containing all the fibres distributed in the anches of the nerve to the skin, continues to give rise, when irri-ed, to the same sensations as are felt when the peripheral parts emselves are affected. Division of a nerve prevents the possibility external impressions on the cutaneous extremities of its fibres ing felt; for these impressions can no longer be communicated the brain: but the same sensations which were before produced external impressions may arise from internal causes. In the ne way may be explained the fact that when part of a limb has en removed by amputation, the remaining portions of the nerves

...shows) it must not
been, from these examples, that the m
criminating the very point in the length c
an irritation is applied. Even in the i
mind perceives the pressure of a nerve at
well as in the seeming sensations derived
the fibres: and in stumps, pain is felt it
seemingly, in the parts removed. In th
also, the mind discerns the very part of a
tated. Thus, if a needle's point be drawn
the back, or the thigh, or any part in whicl
placed, the mind perceives the line of irrit
whereas, if it referred all impressions to the
this mode of irritation should be felt in se
tered about the line, in the points at which
by the needle terminate. So, in the case of
that its whole inner surface is not so covered
fibres that the images of any two points or l
tinct must always fall on different fibres; l
two images fall on different parts of the sam
perceives them as distinct objects, it must be
discern the very point or points of a nerve-
pression falls.

The conclusion from both these sets of fac
natural state of parts, and on the applicatio
the mind can so distinctly discern an impress
in the length of a nerve-fibre as to refer it t
when, as in the case of impressions on the
made at the same

nerves are, or were, commonly received, is further exemplified when the relative position of the peripheral extremities of sensitive nerves is changed artificially, as in the transposition of portions of skin. When, in the restoration of a nose, a flap of skin is turned down from the forehead and made to unite with the stump of the nose, the new nose thus formed has, as long as the isthmus of skin by which it maintains its original connections remains undivided, the same sensations as if it were still on the forehead; in other words, when the nose is touched, the patient feels the impression as if it were derived from the forehead. When the communication of the nervous fibres of the new nose with those of the forehead is cut off by division of the isthmus of skin, the sensations are no longer referred to the forehead; the sensibility of the nose is at first absent, but is gradually developed.

When, in a part of the body which receives two sensitive nerves, one is paralyzed, the other is inadequate to maintain the sensibility of the entire part; the extent to which the sensibility is preserved corresponds to the number of the fibres unaffected by the paralysis. This is a consequence of the isolation and simplicity of the several nerve-fibres, so that, as already observed, even when nerves appear to anastomose, their several fibres continue separate and distinct, as isolated conductors of impressions. Thus, when the ulnar nerve, which supplies the fifth and a part of the fourth finger is divided, the sensibility of those parts is not supplied through the medium of the branches which the ulnar derives from the median nerve; but the fourth and fifth fingers are permanently deprived of sensibility.

Several of the laws of action in *motor nerves* correspond with the foregoing. Thus, the motor influence is propagated only in the direction of the fibres going to the muscles; by irritation of a motor nerve, contractions are excited in all the muscles supplied by the branches given off by the nerve below the point irritated, and in those muscles alone; the muscles supplied by the branches which come off from the nerve at a higher point than that irritated, are never directly excited to contractions. No contraction, for instance, is produced in the frontal muscle by irritating the branches of the facial nerve that ramify upon the face; because that muscle derives its motor nerves from the trunk of the facial previous to these branches. So, again, because the isolation of motor nerve-fibres is as complete as that of sensitive ones, the irritation of a part of the fibres of a motor nerve does not affect the motor power of the whole trunk, but only that of the portion to which the stimulus is applied. And it is because of the same fact that when a motor nerve enters a plexus, and contributes with other nerves to the formation of a nervous trunk proceeding from the plexus, it does not impart motor

...ular nerve-substance,
... the several ganglia which belong to
sympathetic systems. Each of these ne
range of functions, the extent of which
to the number of nerve-fibres that con
organs of the body, and with other nerve
have certain general properties and mod
them as nervous centres.

It is generally regarded as the property
they originate the impulses by which mus
action, and by which the several functions
maintained. Hence, they are often called a
nervous power or force. But the instances
sions can be strictly used are few. It is po
of the heart are the spontaneous sources of
excites its rhythmical contractions; that the m
originate the force exciting the co-ordinate an
first respirations; and that from the spinal co
under which the sphincter ani is held in unif
with these exceptions (if they are such) few
proceed spontaneously from the nervous centre
issue any, except when itself impressed by the
an impression from without; neither without
sions do the other nervous centres produce or
The intestinal ganglia, for example, do not
force necessary to the contractions of the intesti
receive, through their centripetal nerves, the
in the intestinal canal. So, also, the
animal lies motion

Conduction in or through nervous centres may be thus simply illustrated. The food in a given portion of the intestines, acting as a stimulus, produces a certain impression on the nerves in the mucous membrane, which impression is conveyed through them to the adjacent ganglia of the sympathetic. In ordinary cases, the consequence of such an impression on the ganglia is the movement of the muscular coat of that and the near adjacent portions of the canal. But, if irritant substances be mingled with the food, the sharper stimulus produces a stronger impression, and this is *conducted through* the nearest ganglia to others more and more distant, and from all these motor impulses issuing excite a wide-extended and more forcible action of the intestines. Or, even through all the sympathetic ganglia, the impression may be further conducted to the ganglia of the spinal nerves, and through them to the spinal cord, whence may issue motor impulses to the abdominal and other muscles, producing cramp. And yet further, the same morbid impression may be conducted through the spinal cord to the brain, where the mind may perceive it. In the opposite direction, mental influence may be conducted from the brain through a succession of nervous centres—the spinal cord and ganglia, and one or more ganglia of the sympathetic—to produce the influence of the mind on the digestive and other organic functions. In short, in all cases in which the mind either has cognizance of, or exercises influence on, the processes carried on in any part supplied with sympathetic nerves, there must be a *conduction* of impressions through all the nervous centres between the brain and that part. It is probable that in this conduction through nervous centres the impression is not propagated through uninterrupted nerve-fibres, but is conveyed through successive nerve-vesicles and connecting nerve-filaments. In some instances, and when the stimulus is exceedingly powerful, the conduction may be effected as quickly as through continuous nerve-fibres; but with less stimulus it may occupy some minutes in its transit. Thus, *e. g.*, in stimulating the semilunar ganglia of the stomach, movements slowly ensue in the stomach; on touching the heart, all its fibres very soon contract, yet not in that instantaneous manner in which the fibres of a voluntary muscle contract when its nervous trunk is irritated.

But instead of, or as well as, being conducted, impressions made on nervous centres may be *communicated* from the fibres that brought them, to others; and in this communication may be either *transferred*, *diffused*, or *reflected*.

The *transference of impressions* may be illustrated by the pain in the knee which is a common sign of disease of the hip. Here, the impression made by the disease on the nerves of the hip-joint, is conveyed to the spinal cord; there, it is *transferred* to the central ends or connections of the nerve-fibres of the knee-joint. Through

... one sensitive surface ...
... the trunk, a pain will be felt in as ...
some other part of the trunk. And ...
respiratory organs an irritation may be ...
produces is transferred to the nerves of ...
mind perceives the peculiar sensation ...
which best, or almost alone, excites the ...
again, when the sun's light falls strong ...
may be felt in the nose, exciting sneezing ...
primary impression may be conducted as ...
in all it is transferred to a certain set of ...
appear to be in some purposive relation ...
impressed.

The *diffusion* or *radiation of impressions* ... pression received at a nervous centre is diffus ... in the same centre, and produces sensations ... or in an indefinite area around, the part fr ... impression was derived. Hence, as in the ... various kinds of what have been denominat ... tions. Sometimes such sensations are referr ... of the body; as in the shock and tingling of ... some startling noise. Sometimes only the ... rounding the point first irritated participat ... irritation: thus, the aching of a tooth may b ... in the adjoining teeth, and in all the surroun ... the explanation of such a case being, that t ... to the brain by the nerve-fibres of ... the central ends ...

corresponding to those of transference and diffusion to sensitive nerves, are observed in the phenomena of reflection. For, as in transference, the reflection may take place from a certain limited set of sensitive nerves, to a corresponding and related set of motor nerves; as when, in consequence of the impression of light on the retina, the iris contracts, but no other muscle moves. Or, as in diffusion or radiation, the reflection may bring widely-extended muscles into action; as when an irritation in the larynx brings all the muscles engaged in expiration into coincident movement.

It will be necessary to consider in detail so many of the instances of the reflecting power of the several nervous centres that it may be sufficient here to mention only the most general rules of reflex action.

1. For the manifestation of every reflex action, three things are necessary; first, one or more perfect centripetal nerve-fibres, to convey an impression; secondly, a nervous centre to which this impression may be conveyed, and in which it may be reflected; thirdly, one or more centrifugal nerve-fibres, upon which this impression may be reflected, and by which it may be conducted to the contracting tissue. In the absence of either of these three conditions, a proper reflex movement could not take place; and whenever impressions made by external stimuli on sensitive nerves give rise to motions, these are never the result of the direct reaction of the sensitive and motor fibres of the nerves on each other; in all such cases the impression is conveyed by the sensitive fibres to a nervous centre, and is therein communicated to the motor fibres.

2. All reflex actions are essentially involuntary; all may be accomplished independent of the will, though most of them admit of being modified, controlled, or prevented by a voluntary effort. All are perfectly performed without education or previous experience, although some, as coughing and the like, are not well performed unless the will have previously made some preparatory movement.

3. All reflex actions performed in health have a distinct purpose, and are adapted to secure some end desirable for the well-being of the body; but in disease, many of them are irregular and purposeless. As an illustration of the first point may be mentioned movements of the digestive canal, the respiratory movements, the contraction of the eyelids and the pupil to exclude many rays of light, when the retina is exposed to a bright glare. These, and all other normal reflex acts afford, also, examples of the mode in which the nervous centres *combine* and arrange co-ordinately the actions of the nerve-fibres, so that many muscles may act together for the common end. Another instance of the same kind is furnished by the spasmodic contractions of the glottis on the contact of carbonic acid, or any foreign substance, with the internal surface of the

...ation continues; but irritation ap
through one of its centripetal nerves ex
contractions, which last some time af
stimulus.

CEREBRO-SPINAL NERVOU

The physiology of the cerebro-spinal
that of the spinal cord, medulla oblongata
nerves given off from each, and of the gan
will be convenient to speak first of the spin

Spinal Cord and its Ne

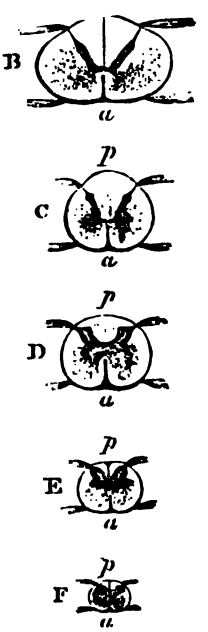
The spinal cord is a cylindriform colun
connected above with the brain through the
oblongata, terminating below, about the fi
vertebra, in a slender filament of gray or v
filum terminale, which lies in the midst
nerves forming the *cauda equina*. The cord
and vesicular nervous substance, of which
externally, and constitutes its chief portion,
pies its central or axial portion, and is so
surface of a transverse section of the cord
somewhat crescentic masses connected togeth
tion, or isthmus.

The spinal cord consists of two exactly syn
in the middle line by a *commis*
posteriorly by a

but is, probably, not formed of them exclusively; nor a mere trunk, like a great nerve, through which they may pass to the brain. It is, indeed, among the most difficult things in structural anatomy to determine the course of individual nerve-fibres through even a short distance of the spinal cord; yet it appears nearly sure that most or all of the fibres of the roots of the spinal nerve terminate in some part of the cord near that in which they first appear connected with it, and do not proceed through it in simple and uninterrupted continuity to the brain. The majority of these fibres, when traced into the cord from the roots of the nerves, appear to pass in a longitudinal direction; and the substance of the cord, after being hardened in spirit, admits of being broken up into longitudinal laminæ, and cannot without much force be split obliquely or transversely.[1] But the distance to which the fibres composing the laminæ run longitudinally from their entrance into the cord is unknown, and probably, by such means as we at present possess, is not determinable. But that they do not pass up to the brain is rendered probable by several circumstances. First, if all, or many of them did so, the thickness of the spinal cord ought to increase from below upwards, in the same proportion as fresh fasciculi of fibres are added to it by each pair of spinal nerves; and the portion nearest the medulla oblongata ought to be thicker than any part below it. But no such progressive increase of thickness is observed: the upper part of the cervical portion of the cord is smaller than the lower part; and both it and the middle of the dorsal portion are smaller than the lumbar portion. The general rule respecting the size of different parts of the cord appears to be, that the size of each part bears a direct proportion to the size and number of nerve-roots given off from itself, and has no relation to the size or number of those given off below it. Thus, the cord is very large in the middle and lower part of its cervical portion, whence arise the large nerve-roots for the formation of the brachial plexuses and the supply of the upper extremities, and again enlarges at the lowest part of its dorsal portion and the upper part of its lumbar, at the origins of the large nerves, which, after forming the lumbar and sacral plexuses, are distributed to the lower extremities.

That such enlargements, occurring at parts of the cord which give off nerves of unusual size, are due to actual increase of nervous substance, has been proved by Volkmann (xv. art. *Nervenphysiologie*). He weighed four pieces of a horse's spinal cord, each seven centimetres long, and taken respectively from below the second, the eighth, the nineteenth, and the thirtieth pairs of nerves, and

[1] But there may be a fallacy in this observation, for it may be that most of the fibres pass transversely in the cord, but lie in vertical planes; as in the fangs of teeth, which split most easily in the longitudinal direction, though all the dentine-tubes, like fibres, run transversely to the axis.



Transverse section of the spinal cord: A. Immediately below the decussation of the pyramids. B [illegible]

[illegible] appeared that the [illegible] substance of the co[illegible] cervical than at the[illegible] portion; which it [illegible] its progress from be[illegible] quantity of the fib[illegible] from the roots of the[illegible] On the other hand, t[illegible] creased weight of th[illegible] corresponding to the [illegible] most numerous nerv[illegible] immediately above a[illegible] make it most probabl[illegible] posing the roots of tho[illegible] from the largest parts[illegible] from any parts higher [illegible]

Moreover, the appea[illegible] sections of the cord ind[illegible] pass inwards towards tl[illegible] either directly or mo[illegible] Many of the fibres thu[illegible] missural, *i. e.*, fibres con[illegible] of the cord, and having[illegible] with the nerve-roots: a[illegible] Stilling and Wallach (c[illegible] because of the low ma[illegible] employed [illegible]

n: such impressions may be as well transmitted through
e-vesicles of the cord and the filaments connecting them.
ese grounds it will be assumed, in what follows, that the
f the roots of the spinal nerves terminate in, or are con-
with, nerve-corpuscles not far from the parts of the cord at
ey severally penetrate it; and that, therefore, the connec-
function between the brain and spinal nerves is maintained
xclusively by means of gray nervous substance, or of fibres
re placed as commissures or *connectors* between the brain
lulla oblongata, and the several parts of the spinal cord.[1]

erves of the spinal cord consist of thirty-one pairs, issuing
e sides of the whole length of the cord; their numbers
nding with the intervertebral foramina, through which they
Each nerve arises by two roots, an anterior and posterior,
r being the largest. The roots emerge through separate
s of the sheath of dura mater surrounding the cord; and
after their emergence, while the roots lie in the interver-
ramen, a ganglion is formed on the posterior root. The
root lies in contact with the anterior surface of the gang-
; none of its fibres intermingle with those
anglion. But immediately beyond the
, the two roots coalesce, and, by the
g of their fibres, form a compound or
pinal nerve, which, after issuing from
rvertebral canal, divides into an anterior
terior branch, each containing fibres from
roots. (Fig. 71.)

Fig. 71.

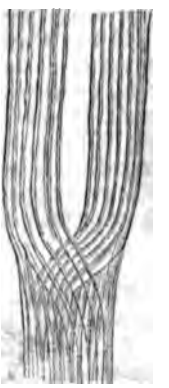


Diagram to show the decussation of the fibres within the trunk of a nerve.—(After Valentin.)

nterior root of each spinal nerve arises
erous separate and converging fasciculi
e anterior column of the cord; the pos-
oot by more numerous parallel fasciculi,
e posterior column, or, rather, from the
r part of the lateral column; for if a
e directed inwards from the groove be-
he middle and posterior columns, the
r roots will remain attached to the former.
erior roots of each spinal nerve consist
ely of motor fibres; the posterior as ex-
y of sensitive fibres. For the knowledge
mportant fact, and much of the conse-
ogress of the physiology of the nervous
science is indebted to Sir Charles Bell. It is proved in

he anatomy of the spinal cord, consult any of the principal sys-
reatises; or Grainger (clii.); Todd (lxxiii. art. *Nervous centres*);
xxxvi.); Stilling and Wallach (clvii.).

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the
the nerves go
and the
right side.
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If co
fee
the muscl

at of injury, cease to be propagated to the brain; and the mind es the power of voluntarily exciting the motor nerves proceed- g from the portion of cord isolated from the brain.

Illustrations of this are furnished by various examples of para- sis, but by none better than by the common paraplegia, or loss of nation and voluntary motion in the lower part of the body, in nsequence of destructive disease or injury of a portion, including e whole thickness, of the spinal cord. Such lesions destroy the mmunication between the brain and all parts of the spinal cord low the seat of injury, and consequently cut off from their con- ction with the mind, the various organs supplied with nerves ming from those parts of the cord. But, if this lower portion the cord preserves its integrity, the various parts of the body pplied with nerves from it, though cut off from the brain, will vertheless be subject to the influence of the cord, and, as pre- ntly to be shown, will indicate its other powers as a nervous ntre.

From what has been already said, it will appear probable that conduction of impressions along the cord is effected (at least a part of the distance) through the gray substance, *i. e.*, through nerve-corpuscles and filaments connecting them. But there is son to believe that all parts of the cord are not alike able to con- t all impressions; and that, rather, as there are separate nerve- es for motor and for sensitive impressions, so, in the cord, sepa- e and determinate parts serve to conduct the same impressions. e consideration of this point involves the question of the *func- ns of the columns of the cord*. The question is, whether the erior and posterior columns correspond to the anterior and pos- ior roots respectively: whether the anterior columns contain y motor, the posterior only sensitive fibres. It was difficult to ide this, even when it was supposed that the fibres of the roots the nerves were continued uninterruptedly to the brain: and difficulty is much increased if we believe that they are not so ntinued, and that conduction may take place as well through the y substance of the cord as through its fibres.

Experiments, especially those of Longet (cxxxvi.) and Van Deen riii.), have shown that irritations of the anterior columns of the nal cord are followed by convulsive movements of all the parts plied with motor nerves from and below the irritated part, but e rise to no manifestations of pain: while irritation of the poste- r columns appears to cause excruciating pain, without producing r muscular movement besides such as may be the result of voli- n, or the reflection of the stimulus from the irritated cord to the ts of motor nerves. Again, when the spinal cord is completely ided, irritation of the posterior columns of the lower part which ut off from the brain, produces no effect: irritation of the ante-

... of voluntary movement over t
below the point of division is complete
same parts being unimpaired. When
divided, sensation in the parts supplied
injured point is lost, while the power of
remains perfect (Van Deen). [It has b
Séquard, that when the posterior column
is a loss of sensibility in the opposite side
a crossing of the fibres of the sensory,
tract.]

The results of these experiments would
effects of the division of the anterior or p
cord are exactly the same as those of div
posterior roots of the spinal nerves, and th
be justified in calling the anterior the motor
sensitive, columns of the cord. Yet there
tion. For the posterior roots of the spinal
(as already stated), not with the posterior
posterior part of the lateral columns; and
experiments, nor the results of disease, can
as to discern the difference of the effects of
columns, from those of the immediately-ad
lateral columns. Neither is it likely that th
are the sole, or even the principal, conduct
the most, therefore, we should not be justi
than that the posterior half of the cord corre
tive roots, the anterior with the motor
though there may be little
hold as this

for example, in which complete loss of motion, without any impairment of sensation, was an accompaniment of lesion of the posterior columns of the cord, the anterior being apparently entire (Stanley, xli. vol. xxiii.; Webster, xli. vol. xxvi.).

The foregoing observations have related only to the conduction of impressions *along* the cord; they may also be conducted in some directions *across* it. Thus, if the brain and medulla oblongata be removed, irritation of either posterior column of the upper end of the cord will cause general movements of muscles, the impression being conveyed across to the anterior columns and roots; for the movements do not happen if the anterior roots are divided. If one half of the cord be divided at a certain part, and the other half at a certain distance from that part, impressions (at least sensitive ones) may be conducted through the intermediate portion of the cord from one side to the other (Van Deen); and this may be effected though only a portion of the gray substance be left to connect the portions of cord above and below. But impressions do not seem to be conveyed from the anterior columns to the posterior, nor from one anterior column to the other; so that, as in the case already cited from Begin, after the division of one anterior column, including the anterior part of the gray matter in it, the will has no power over the muscles deriving nerves from or below the injured part of the column.[1]

2. In the second place, the spinal cord as a nervous centre, or rather as an aggregate of many nervous centres, has the power of *communicating impressions* from fibre to fibre in the several ways already mentioned (p. 299).

Examples of the *transference* and *radiation* of impressions in the cord have been given; and that the transference at least takes place in the cord, and not in the brain, is nearly proved by the cases of pain felt in the knee, and not in the hip, in diseases of the hip; of pain felt in the urethra or glans penis, and not in the bladder, in calculus; for if both the primary and the secondary or transferred impressions were in the brain, both should be always felt. Of radiation of impressions there are, perhaps, no means of deciding whether they take place in the spinal cord or in the brain: but the analogy of the cases of transference makes it probable that the communication is, in this, also, effected in the cord.

[1] For a complete discussion of this subject, and for the arguments in favour of the posterior columns of the cord being composed of fibres forming commissural connections between its several parts, see Todd (lxxiii. art. *Nervous Centres*; and clix). The best evidence for the sensitive and motor functions being appropriate to the posterior and anterior columns is in Longet (xxxvi). Many interesting facts are in Sir Charles Bell's works (cxlii.); Müller (xxxii.); and Grainger (cliii.).

(p. 600). These points, a
power operates in the production of th
of the body, have now to be further illu
scribed in terms adapted to the general
pressions in nervous centres, avoiding all
to imply that the power of the spinal cor
in kind from that of all other nervous cer

The occurrence of movements under th
cord, and independent of the will, is well
of swallowing, in which a portion of food ca
into the fauces, is conveyed by successive
of the constrictors of the pharynx and mu
phagus into the stomach. These contracti
stimulus of the food on the centripetal ner
œsophagus being first conducted to the spina
longata, and thence reflected through the moto
All these movements of the pharynx and œ
tary; the will cannot arrest them or modify
mind has a certain consciousness of the food
less as the food passes further, yet that this
act of deglutition, is shown by its occurring
the mind is completely removed; as when
the fauces or pharynx during a state of c
brainless animal (Grainger, clii.).

So, also, for example, under the influence
involuntary and unfelt muscular contractio
is maintained when the mind is completel
sleep, but ceases when the
cannot be

, as in decapitated animals, and in cases of injuries or dis-
ıo affecting the spinal cord as to divide or disorganize its
thickness at any part whose perfection is not essential to life.
when the head of a lizard is cut off, the trunk remains stand-
the feet, and the body writhes when the skin is irritated.
animal is cut in two, the lower portion can be excited to
ı as well as the upper portion; the tail may be divided into
l segments, and each segment, in which any portion of spinal
ɜ contained, contracts on the slightest touch; even the ex-
y of the tail moves as before, as soon it is touched. All the
ıs of the animal in which these movements can be excited,
n some part of the spinal cord; and it is evidently the cause
motions excited by touching the surface; for they cannot be
d in parts of the animal, however large, if no cord is con-
in them. Mechanical irritation of the skin excites not the
ɜst motion in the leg when it is separated from the body;
e extremity of the tail moves as soon as it is touched. With
me power of the spinal cord in reflecting impressions, an eel,
rog, or any other cold-blooded animal, will move long after it
ɔrived of its head, and when, however much the movement
ndicate purpose, it is not probable that consciousness or will
ıy share in them. And so, in the human subject, or any
·blooded animal, when the cord is completely divided across, or
eased at some part that the influence of the mind cannot be
yed to the parts below it, the irritation of any part of the
e, supplied by nerves given off from the cord below the seat
ury, is commonly followed by spasmodic and irregular reflex
ment, even though in the healthy state of the cord such invo-
·y movements could not be excited when the attention of the
was directed to the irritating cause.
the fact last mentioned is an illustration of an important dif-
ɜe between the warm-blooded and the lower animals in regard
ɜ reflecting power of the spinal cord (or its homologue in the
tebrata), and the share which it and the brain have respect-
in determining the several natural movements of the body.
ı, for example, a frog's head is cut off, the limbs remain in
ume a natural position; resume it when disturbed; and when
bdomen or back is irritated, the feet are moved with the
est purpose of pushing away the irritation. It is as if the
of the animal were still engaged in the acts.[1] But, in divi-

ıe evident adaptation and purpose in the movements of the cold-
d animals have led some to think that they must be conscious and
e of will without their brains. But purposive movements are no
of consciousness or will in the creature manifesting them. The
ents of the limbs of headless frogs are not more purposive than the
ents of our own respiratory muscles are; in which we know that
· will nor consciousness is at all times concerned.

sion of the human spinal cord, the lower extremities fall into any position that their weight and the resistance of surrounding objects combine to give them: if the body is irritated, they do not move towards the irritation; and if themselves are touched, the consequent movements are disorderly and purposeless. Now, if we are justified by analogy in assuming that the will of the frog cannot act more than the will of man through the spinal cord separated from the brain, [illegible] admitted that many more of the natural and purp[illegible]ts of the body can be performed under the sole influ[illegible] in the frog than in man; and what is true in th[illegible] these two species is generally true also of the whe[illegible] blooded as distinguished from warm-blooded-anim[illegible], indeed, be assumed that the acts of standing, [illegible] movements which decapitated cold-blooded ani[illegible] also always, in the entire and healthy state, pe[illegible]ly and under the sole influence of the cord; but it is probable that such acts may be, and commonly are, so performed, the mind of the animal having only the same kind of influence in modifying and directing them, as the mind of man has in modifying and directing the movements of the respiratory muscles.

The fact that such movements as are produced by irritating the skin of the lower extremities in the human subject, after division or disorganization of a part of the spinal cord, do not follow the same irritation when the mind is active and connected with the cord through the brain, is, probably, due to the mind ordinarily perceiving the irritation and instantly controlling the muscles of the irritated and other parts; for, even when the cord is perfect such involuntary movements will often follow irritation if it be applied when the mind is wholly occupied. When, for example, one is anxiously thinking, even slight stimuli will produce involuntary and reflex movements. So, also, during sleep such reflex movements may be observed when the skin is touched or tickled; for example, when one touches with a finger the palm of the hand of a sleeping child, the finger is grasped—the impression on the skin of the palm producing a reflex movement of the muscles which close the hand. But when the child is awake, no such effect is produced by a similar touch.

On the whole, it may, from these and like facts, be concluded that the proper reflex acts, performed under the influence of the reflecting power of the spinal cord, are essentially independent of the brain, and may be performed perfectly when the brain is separated from the cord: that these include a much larger number of the natural and purposive movements of the lower animals than of the warm-blooded animals and man; and that over nearly all of them the mind may exercise, through the brain, some control

determining, directing, hindering, or modifying them, either by direct action or by its power over associated muscles.

In this fact, that the reflex movements from the cord may be perfectly performed without the intervention of consciousness or will, yet are amenable to the control of the will, we may see their admirable adaptation to the well-being of the body. Thus, for example, the respiratory movements may be performed while the mind is, in other things, fully occupied, or in sleep powerless; yet, in an emergency, the mind can direct and strengthen them; and it can adapt them to the several acts of speech, effort, &c. Being, for ordinary purposes, independent of the will and consciousness, they are performed perfectly, without experience or education of the mind; yet they may be employed to other and extraordinary uses when the mind wills, and so far as it acquires power over them. Being commonly independent of the brain, their constant continuance does not produce weariness; for it is only in the brain that it or any other sensation can be perceived.

The subjection of the muscles to both the spinal cord and the brain makes it difficult to determine in man what movements or what share in any of them can be assigned to the reflecting power of the cord. The fact that, after division or disorganization of a part of the cord, movements, and even forcible though purposeless ones, are produced in the lower limbs when the skin is irritated, proves that the spinal cord can supply nervous force for the action of the muscles that are, naturally, most under the control of the will: and it is, therefore, not improbable that, for even the voluntary action of those muscles, when the cord is perfect, it may supply the force, and the will the direction. For instances in which it supplies both force and direction, that is, both excites and determines the combination of muscles, may be mentioned the acts of the abdominal muscles in vomiting and voiding the contents of the bladder and rectum: in both of which, though, after the period of infancy, the mind may have power of postponing or modifying the act, there are all the evidences of reflex action; namely, the necessary precedence of a stimulus, the independence of the will, and, sometimes, of consciousness, the combination of many muscles, the perfection of the act without the help of education or experience, and its failure or imperfection in disease of the lower part of the cord. The emission of semen is equally a reflex act governed by the spinal cord: the irritation of the glans penis, conducted to the spinal cord and thence reflected, excites the successive and co-ordinate contractions of the muscular fibres of the vasa deferentia and vesiculæ seminales, and of the bulbo-cavernosi and other muscles of the urethra; and a forcible expulsion of semen takes place, over which the mind has little or no control, and which, in cases of paraplegia, may be unfelt. The erection of the penis also, as already explained

(page 121), appears to be in part the result of a reflex contraction of the muscles by which the veins returning the blood from the penis are compressed. Irritation of the vagina in sexual intercourse appears also to be propagated to the spinal cord, and thence reflected to the motor nerves supplying the Fallopian tubes. The involuntary action of the uterus in expelling its contents during parturition, is also of a purely reflex kind, dependent in part upon the spinal cord, though in part also upon the sympathetic system: its independence of the brain is proved by cases of delivery in paraplegic women, as is abundantly shown in the use of chloroform.

Besides these acts, performed under the influence of the reflecting power of the cord, others are manifested in accidents; such as the involuntary movements of the limbs and other parts, to guard the body against sudden danger. When, for example, a limb is pricked, it is instantly and involuntarily withdrawn from the instrument of injury; a threatened blow on the face causes involuntary closure of the eye. And the same preservative tendency of the reflex power of the cord is shown in the outstretched arms when falling forwards, and their reversed position when falling backwards.

To these instances of spinal reflex action some add yet many more, including nearly all the acts which seem to be performed unconsciously, such as those of standing, walking, and the like. But these are not involuntary acts; they are not accomplished without the active co-operation of the brain, for they are impossible in coma, sleep, paraplegia, and complete mental abstraction; they all require education for their perfection; their force is not proportioned to any external stimulus exciting them; they produce weariness; in short, they appear to be only examples of how small an amount of attention and will are necessary for the performance of habitual acts.

The phenomena of spinal reflex actions in man are much more striking and unmixed in cases of disease. In some of these, the effect of a morbid irritation, or a morbid irritability of the cord, is very simple; as when the local irritation of sensitive fibres, being propagated to the spinal cord, excites merely local spasms—spasms, namely, of those muscles, the motor fibres of which arise from the same part of the spinal cord as the sensitive fibres that are irritated. Of such a case, we have instances in the spasms and tremors of limbs on which a severe burn is inflicted, &c.

In other instances, in which we must assume that the cord is morbidly more irritable, *i. e.*, apt to issue more nervous force than is proportionate to the stimulus applied to it, a slight impression on a sensitive nerve produces extensive reflex movements. This ap-

pears to be the condition in tetanus, in which a slight touch on the skin may throw the whole body into convulsions. A similar state is induced by the introduction of strychnia, and, in frogs, of opium, into the blood; and numerous experiments on frogs thus made tetanic have shown that the tetanus is wholly unconnected with the brain, and depends on the state induced in the spinal cord.

It may have seemed to be implied that the spinal cord, as a single nervous centre, reflects alike from all parts all the impressions conducted to it. But it is more probable that it should be regarded as a collection of nervous centres united in a continuous column. This is made probable by the fact that segments of the cord may act as distinct nervous centres, and excite motions in the parts supplied with nerves given off from them; as well as by the analogy of certain cases in which the muscular movements of single organs are under the control of certain circumscribed portions of the cord. Thus Volkmann (lxxx. 1844) has shown that the rhythmical movements of the anterior pair of lymphatic hearts in the frog depend upon nervous influence derived from the portion of spinal cord corresponding to the third vertebra, and those of the posterior pair on influence supplied by the portion of cord opposite the eighth vertebra. The movements of the hearts continue, though the whole of the cord, except the above portions, be destroyed; but on the instant of destroying either of these portions, though all the rest of the cord is untouched, the movements of the corresponding hearts cease. What appears to be thus proved in regard to two portions of the cord, may be inferred to prevail in other portions also; and the inference is reconcilable with most of the facts known concerning the physiology of the cord.

It might be supposed that each portion of the cord is as the nervous centre of a certain region, receiving and issuing impressions from and to the several nerve-fibres immediately connected with it. But some experiments by Engelhardt and Harless have made it probable (if the case of frogs may be taken as an example of a general truth), that different portions of the length of the cord are assigned for the government of different kinds of movements. The results of Harless's experiments may be thus expressed, in a scheme in which each number represents that of the vertebra opposite to which the irritation was applied to the spinal cord:—

Irritation at the . .	1st vertebra.	No movement.
Flexion of upper extremities decreasing as the irritation is applied higher.	2d "	Flexion of lower extremities decreasing as the irritation is applied lower.
	3d "	
	4th "	

...nner of Harless's experim...
portion of the frog's cord cap...
motor nerves of the extremities...
vertebra. For, by cutting awa...
power of reflecting so as to pr...
tremities is lost, when the sectio...
that of reflecting to the upper ex...
the fourth vertebra.

The influence of the spinal co...
already mentioned. It maintain...
traction, so that, except in the act...
anus is always closed. This infl...
common reflex action in being in...
act on the muscle to make it contr...
tion, and in that the constant actio...
diminished in sleep, nor productiv...
different from ordinary reflex acts...
this respect it resembles that condit...
called *Tone*,[1] or passive contraction...
appear to be when not active in...
called inactive, they appear to be...
tainly are not relaxed, as they are...
spinal cord is destroyed. This t...
trunk and limbs seems to depend...
traction of the sphincter ani does...
or removal of the brain, the tone of...
the limbs feel firm, as dur...
destroyed, th...

clii.); Newport (xliii. 1844); Volkmann (lxxx. 1838); ıdd (xli. vol. xxii.); Carpenter (cxxxi.); Todd (lxxiii. *ıs Centres*); Barlow (lxxi. vol. xli.).

THE MEDULLA OBLONGATA.

Its Structure.

lulla oblongata is a mass of gray and white nervous sub- ained within the cavity of the cranium, forming part of c prolongation of the spinal cord, and connecting it with The gray substance which it contains is situated in the ıriously divided into masses and laminæ by the white or ıstance, which is arranged partly in external columns, in fasciculi traversing the central gray matter. The ılongata is larger than any part of the spinal cord. Its e pyriform, enlarging as they ıwards the brain, continuous of the spinal cord, more pro- ın they are, and separated from r by deeper grooves. In front, rresponding with the anterior the cord, and named *anterior* or *corpora pyramidalia* (Fig. re separated from each other by rior median fissure, at the bot- ch fibres appear decussating, *i.* one another and changing sides. ınner, nearly all the fibres of ıid pass over, and turning back- ɔme continuous with the op- al columns of the cord; those ıot decussate are directly con- th the anterior column of the ced upwards, the fibres of the ramids pass through the inferi- ıe pons Varolii, and then, form- er part of the crura cerebri, pro- gh the optic thalami and cor- a to be distributed in the substance of the cerebral ɛs.[1] (Fig. 74, *p*.)

Fig. 72.

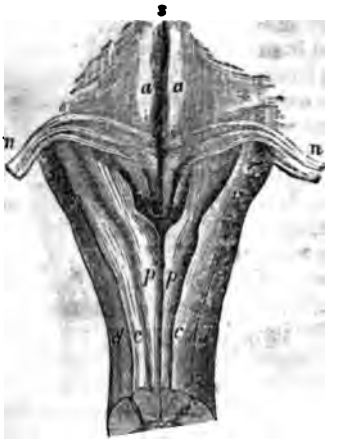
Front view of the medulla oblongata: *p, p.* Pyramidal bodies, decussating at *d*. *o, o.* Olivary bodies. *r, r.* Restiform bodies. *a, a.* Arciform fibres. *v.* Lower fibres of the Pons Varolii.

ression "continuous fibres," and the like, appear to be usually as meaning that certain primitive nerve-fibres pass without in- rom one part to the other of those named. But such continuity fibres through long distances in the nervous centres is very far . The apparent continuity of fasciculi (which is all that dissec- trace) is explicable on the supposition that many comparatively

corpora olivaria are formed of
in fibres, and elevating them.

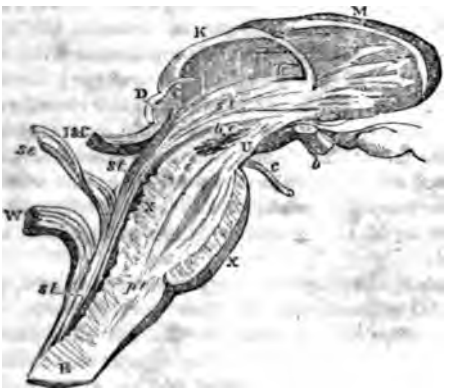
Immediately behind the corp
depressed tract of fibrous mat
tract, because its fibres, instead
to the cerebrum, go outwards t
the cerebellum. (Fig. 74.) Th
tracts, and are interesting in that

Fig. 73.



by the lower angle of the fourth ventricle. (Fig. 73.) The fibres of these tracts are continuous below, with a narrow column, which, about the middle of the cervical portion of the cord begins to be, as it were, set off from the posterior columns, by a narrow groove. They seem to pass upwards longitudinally through the pons, and thence in connection with the processes that unite the cerebrum with the cerebellum, under the corpora quadrigemina, and into the crus cerebri of the opposite side. (Fig. 74, w.)

Fig. 74.



This drawing is from a dissection made on a piece of brain, which had been hardened in Spirit. It exhibits the course of the sensory columns from the medulla oblongata to the thalamus. c. Anterior optic tubercle. D. Posterior ditto. J & C. Inter-cerebral commissure, *c* processus à cerebello ad testes. R. Spinal cord. K. Thalamus optici. M. Corpus striatum. t. Crus cerebri. W. Corpus restiforme. X, X. Pons Varolii. *b*. Optic nerve. *c*. Third pair. *l c*. Locus niger. *p t*. Pyramidal, or motor tract. *s t, s t, s t*. Sensory tract—the posterior third of the antero-lateral column. *s c*. Sensory root of the fifth pair of nerves.

Deeper than the posterior pyramidal tracts, and forming slight elevations on each side of the middle line of the fourth ventricle, are other two, named the *round tracts*. They appear to be composed of the middle or axial portions of the anterior and lateral columns, which, as they pass upwards, are, as it were, exposed from behind, by the divergence of the restiform and posterior pyramidal tracts. The round tracts pass longitudinally through the pons, and thence proceed, decussating, under the corpora quadrigemina, to the fibres of the crura cerebri.

The continuation of the gray matter of the cord, into the medulla oblongata, forms the gray matter covering the floor of the fourth ventricle, and diffused beneath its surface. The separation of the posterior internal, and restiform tracts leaves open, in the

racing of the continuities of its spinal cord lies, chiefly, in the fa arise from both. Thus, from the tinuation in the crura cerebri, aris of cerebral nerves. From the gr mids and the olivary tracts (a groo all the motor roots of the spinal n hypoglossal nerve. From the late of fibres continuous with the ante cord, arise the motor facial, and fou from the front of the restiform tra the groove between the posterior an spring the roots of the sensitive gl gastric nerves.

There is, thus, the closest analogy i in the general endowments of thei medulla oblongata and the spinal cor form appears due, chiefly, first, to the decussation of the several columns, with the cerebellum or the cerebrum; tion of new quantities of gray matt other parts, in adaptation to the high influence, which the medulla oblonga cises.

Functions of the Medu

In its functions, the medulla cord chiefly

tracts, and sensitive ones along its posterior and restiform tracts. This, which might be expected from the continuity of the columns, in the two parts, and the similarity of the nerves arising from them, is further rendered probable by experiments and the results of disease. Magendie divided one of the anterior pyramidal tracts of the medulla oblongata, and observed complete loss of the motor power over one-half of the body, while its sensation seemed to be unimpaired (cxli. t. i. p. 285). In Longet's experiments on dogs and rabbits, irritation of the anterior pyramids appeared to be unproductive of pain, but the slightest touch of the restiform bodies elicited signs of acute suffering (cxxxvi. t. i. p. 400). Among the corresponding evidences furnished by disease, Lebert mentions a case in which great disorder of the power of motion with unimpaired sensation, resulted from an affection of the anterior portion of the medulla oblongata; the posterior portion being apparently unharmed (cxxxvi. t. i. p. 407).

The decussation of part of the fibres of the anterior pyramids of the medulla oblongata, and their crossing into the lateral tracts of the opposite side of the cord, make it probable that the motor impressions proceeding from the brain would, by traversing one pyramid, pass across to the opposite side of the spinal cord. Thus are explained the phenomena of cross-paralysis, as it is termed, *i. e.*, of the loss of motion, in cerebral apoplexy, being always on the side opposite to that on which the effusion of blood has taken place. But, in the present state of the anatomy of the medulla oblongata, it is not possible to explain why the loss of sensation is also on the side opposite the injury or disease of the brain; for there is no evidence of a decussation of posterior fibres nearly equal to that which ensues among the anterior fibres of the medulla oblongata and upper part of the cord. See on the subject, Longet (cxxxvi. t. i. p. 400).

The functions of the medulla oblongata as a *nervous centre* are more immediately important to the maintenance of life than those of any other part of the nervous system, since from it alone issues the nervous force necessary for the performance of respiration and deglutition. It has been proved by repeated experiments, especially by those of Legallois (cxxxix. t. i. p. 64), Flourens (cxl.), and Longet (cxxxvi.), that the entire brain may be gradually cut away in successive portions, and yet life may continue for a considerable time, and the respiratory movements be uninterrupted. Life may, also, continue when the spinal cord is cut away in successive portions from below upwards as high as the point of origin of the phrenic nerve, or in animals without a diaphragm, such as birds or reptiles, even as high as the medulla oblongata. In Amphibia, these two experiments have been combined: the brain being all removed from above, and the cord from below; and so long as the

injury and disease in men prove t
on animals. Numerous instances a
Charles Bell (cxlii.), in which injury
gata has produced instantaneous deatl
injury of it, or of the part of the c
origin of the phrenic nerve, that deatl
fractures and diseases with sudden dis
vical vertebra.

The centre whence the nervous force
bined respiratory movements appears to
that part of the medulla oblongata from
nerves arise; for with care the medulla
to within a few lines of this part, and its
without the stoppage of respiration; bu
when this part is invaded. This is not
the pneumogastric nerves is essential to th
for both these nerves may be divided withc
than a retardation of these movements. T
may safely be, that this part of the medulla
centre wherein the impulses producing th
originate, and whence they issue in rhyth

The power by which the medulla oblo
bines the action of various muscles for th
is an instance of the power of *reflection*
common with all nervous centres. Its ge
well as the degree in which the mind mav
and the number of nerves and
of the medul

of breathing." When they are both divided the respiration becomes slower (J. Reid, xciv. 1838), as if the necessity were less acutely felt: but it does not cease, and therefore other nerves besides them must have the power of conducting the like impression. The experiments of Volkmann make it probable that all centripetal nerves possess it in some degree, and that the existence of imperfectly aerated blood in contact with any of them acts as a stimulus, which, being conveyed to the medulla oblongata, is reflected to the nerves of the respiratory muscles: so that respiratory movements do not wholly cease so long as any centripetal nerves, and any nerves supplying muscles of respiration, are both in continuous connection with the respiratory centre of the medulla oblongata.

The wide extent of connection which belongs to the medulla oblongata as the centre for the respiratory movements, is further shown by the fact that impressions, by mechanical and other ordinary stimuli, made on many parts of the external or internal surface of the body, may induce respiratory movements. Thus involuntary inspirations are induced by the sudden contact of cold with any part of the skin, as in dashing cold water into the face; irritation of the mucous membrane of the nose produces sneezing; irritation in the pharynx, œsophagus, stomach, or intestines, excites the concurrence of the respiratory movements to produce vomiting; violent irritation in the rectum, bladder, or uterus, gives rise to a concurrent action of the respiratory muscles, so as to effect the expulsion of the fæces, urine, or fœtus.

The medulla oblongata is also the centre whence are derived the motor impulses enabling the muscles of the palate, pharynx, and œsophagus to produce the successive co-ordinate and adapted movements necessary to the act of *deglutition* (see p. 163). This is proved by the persistence of the power of swallowing, after destruction of the cerebral hemispheres and cerebellum; its existence in anencephalous monsters; the power of swallowing possessed by marsupial embryos before the brain is developed; and by the complete arrest of the power of swallowing when the medulla oblongata is injured in experiments. But the reflecting power herein exercised by the medulla oblongata is of a much simpler and more restricted kind than that exercised in respiration; it is, indeed, not more than a simple instance of reflex action by a segment of the spinal axis, receiving impressions for this purpose from only a few centripetal nerves, and reflecting them to the motor nerves of the same organ. The incident or centripetal nerves in this case are the branches of the glosso-pharyngeal, and, in a subordinate degree, those of the cervical nerves, which combine to form the pharyngeal plexus; and the nerves through which the motor impressions to the fauces and pharynx are reflected are the pharyngeal branches of the vagus, and,

perfect and in connection with resp
the brain above it is removed, there is
sation, or will, or of any mental act i
the experiment, than there is when o
The movements are all involuntary an
oblongata has therefore no claim to be
the mind, or as the seat of sensation or
are connected with parts next to be desc

It may be here observed, that the part
which acts as a nervous centre, may conti
tion after the part which is only a cond
Thus, patients with apoplexy or compress
on breathing, though, if they have any
power, it is so little, that we cannot suppos
conveyed, in either direction, through the m
so, when ether or chloroform has been inhal
well, though they are so wholly insensible,
lost all voluntary power, that we cannot
oblongata to conduct either to or from the
of the brain.

Moreover, it appears that by such inha
fleeting power of the medulla oblongata
yet its power in the respiratory movements
patients completely affected with chlorofor
eyelids ceases, and irritation of the phary
usual movements of swallowing, or the cl
that blood may run quietly
lungs); yet

cipally of transverse fibres connecting the two hemispheres of the cerebellum, and forming its principal commissure. But it includes, interlacing with these, numerous longitudinal fibres which connect the medulla oblongata with the cerebrum, and transverse fibres which connect it with the cerebellum. Among the longitudinal fibres of the pons, the inferior and some of the superior connect the anterior pyramidal, the olivary, and the round tracts of the medulla oblongata with the cerebrum; while others of the superior fibres connect with it the posterior and internal columns of the medulla. By the transverse fibres of the pons, a part of the anterior and lateral tracts, and, apparently, the whole of the restiform tracts of the medulla oblongata, are connected with the cerebellum; so that the pons may be regarded as containing the several means, 1st, by which the cerebrum is connected with all the tracts of the medulla oblongata, except the restiform and lateral; 2d, by which the cerebellum is connected with these two tracts; 3d, those by which its two hemispheres are united; and, lastly (if we may reckon the *processus arciformes* or *ponticulus* as part of the pons), the fibres by which the anterior pyramidal and the restiform tracts of the medulla oblongata are connected with each other. And among the fasciculi of nerve-fibres by which these several parts are connected, the pons also contains abundant gray or vesicular substance, which appears irregularly placed among the fibres, and fills up all the interstices.

As a conductor of impressions, we may consider the pons, as its anatomy would suggest, to contain the continuation of the conducting portion of the medulla oblongata to the cerebrum and cerebellum. Longet (cxxxvi. t. i. p. 427) says that acute pain is produced by touching its posterior part, but, by irritation of its interior, no pain, but convulsions of the face, limbs, and other parts. But the results or experiments respecting its conducting power are confused by those of the injuries of the crura cerebri and crura cerebelli, which will be presently referred to.

As a nervous centre, it appears probable that the pons may be regarded as the first, or lowest portion of the encephalon, in which, when the rest of the brain is removed, the mind may have sensation of impressions or exercise the will. When all the encephalon above the medulla oblongata is removed from a warm-blooded animal, it appears absolutely insensible, and deprived of all voluntary power; it only breathes and has other, generally purposeless, reflex movements of the trunk and limbs. But experiments of Flourens and Longet show that when the pons is left, with the medulla oblongata, indications of sensibility may be elicited, and the movements that follow them are characteristic of purpose and will. Thus, in the experiments on rabbits and puppies, the cere-

[illegible] movement is caused as soon
therefore, be assumed either t
which the mind may receive an
is a part or whether the higher an
the medulla. Thought or any pa
may be the true explanation of
for they are not more indicative
those of the decapitated frog, in v
believe that neither of these ment
lieve that these movements are vo
tions, appears more accordant with
nation of the reflex function to the
blooded animals.

STRUCTURE AND PHYSIOLOGY

The more one ascends towards the
spinal system, the more does it becon
ture beyond that of external form a
more difficult to connect even the m
the functions of the part. With ref
appears, at present, so complete a v
anatomy and its physiology, that it
of this work to say more of the form
or hemispheres of which it consists a
tions of fibres combined in a *crus*
derived from three sources, [illegible]
medulla ob[illegible]

ove, by a continuity of both gray and white substance, arranged
the same general plan as in themselves, in the *vermiform pro-*
ss.

The physiology of the cerebellum may be considered in its rela-
on to sensation, voluntary motion, and the instincts or higher
culties of the mind. It is itself insensible to irritation, and may
all cut away without eliciting signs of pain (Longet, cxxxvi. t.
733, and others). Yet, if any of its crura be touched, pain is in-
sted; and, if the restiform tracts of the medulla oblongata be
itated, the most acute suffering is produced. Its removal or dis-
ganization by disease is, also, generally unaccompanied with loss
disorder of sensibility; animals from which it is removed can
ell, see, hear, and feel pain, to all appearance, as perfectly as
fore (Flourens, cxl.; Magendie, cxli. &c.). So that, although
e restiform tracts of the medulla oblongata, which are themselves
sensitive, and the continuations of the especially sensitive co-
mns of the spinal cord, enter the cerebellum, it cannot be re-
rded as a principal organ of sensibility.

In reference to motion, the experiments of Longet and most
hers agree that no irritation of the cerebellum produces move-
nts of any kind; and these are probably correct, though Valentin
ys that irritation of it (as of some other parts of the encephalon)
oduces movements of the stomach, intestines, urinary bladder,
d vasa deferentia. More uniform and remarkable results are
oduced by removing parts of the cerebellum. Flourens, whose
periments have been abundantly confirmed by those of Bouillaud
lxxvi.), Longet (cxxxvi. t. i. 740), and others, extirpated the
rebellum in birds by successive layers. Feebleness and want of
rmony of the movements were the consequence of removing the
perficial layers. When he reached the middle layers, the animals
came restless without being convulsed; their movements were
olent and irregular, but their sight and hearing were perfect.
y the time that the last portion of the organ was cut away, the
imals had entirely lost the powers of springing, flying, walking,
anding, and preserving their equilibrium. When an animal in
is state was laid upon its back, it could not recover its former
sture; but it fluttered its wings, and did not lie in a state of
apor; it saw the blow which threatened it, and endeavored to
oid it. Volition, sensation, and memory, therefore, were not
st, but merely the faculty of combining the actions of the muscles;
d the endeavors of the animal to maintain its balance were like
ose of a drunken man.

The experiments afforded the same results when repeated on all
sses of animals, and from them and the others before referred to
ourens inferred that the cerebellum belongs neither to the sensi-

—tomy. The tables of M. Ser
exceptions, in the ascending scal
undergoes a general increase of
preponderance over the size of t
say that its development is unc
faculty of combining muscular mo
classes of Vertebrata, the species w
most frequent and exact combin
those whose cerebella are most dev
cord.

On the strength of all these evid
has been generally adopted. But
bellum is the organ for the perceptio
of the sensations derived from mus
acquires that knowledge of their acti
essential to the exercise of the will u
ted that all the facts just referred to
hypothesis as on that of the cerebel
bining movements; and this hypothe
than M. Flourens's with the very
cerebellum and the posterior column

Gall was led to believe that the cer
cal love, or, as Spurzheim called it,
is generally received by phrenologist
first, several cases in which atrophy
passion have been the consequence of
wounds of its substance; secondly
cerebellum has

loss of sexual passion followed the injury of the cerebellum
e testes began to diminish. The cases of disease of the
m do not prove more; for the same affections of the genital
e more generally observed in diseases, and in experimental
s, of the medulla oblongata and upper part of the spinal
See Longet, cxxxvi. t. i. 762.)
ets drawn from craniological examination will receive the
ven to the system of which they are a principal evidence.
pposition to them it must be stated, that there has been
f complete disorganization or absence of the cerebellum
loss of sexual passion (Combiette, clx. 1831, Longet, and
ier); that the cocks from whom M. Flourens removed the
m showed sexual desire, though they were incapable of
g it; and that among animals there is no proportion ob-
between the size of the cerebellum and the development
exual passion. On the contrary, many instances may be
d in which a larger sexual appetite coexists with a smaller
m; as, *e. g.*, that rays and eels, which are among the fish
nlate, have no laminæ on their almost rudimental cerebella;
codfish, that do not copulate, but deposit their generative
the water, have comparatively well-developed cerebella.
the Amphibia, the sexual passion is exceedingly strong in
l toads; yet the cerebellum is only a narrow bar of nervous
e. Among birds, there is no enlargement of the cerebel-
he males that are polygamous: the domestic cock's cere-
s not larger than the hen's, though his sexual passion must
ated as many times greater than hers. Among Mammalia,
rule holds; and in this class the experiments of M. Las-
ave plainly shown that the abolition of the sexual passion
val of the testes in early life is not followed by any dimi-
f the cerebellum; for in mares and stallions the average
weight of the cerebellum is 61 grains, and in geldings 70
and its proportionate weight, compared with that of the
n, is, on an average, as 1:6.59 in mares; as 1:5.97 in
, and only as 1:7.07 in stallions.
ie whole, therefore, it appears advisable to wait for more
before concluding that there is any peculiar and direct
on between the cerebellum and the sexual instinct or sexual
From all that has been observed, no other office is mani-
than that of regulating and combining muscular move-
r of enabling them to be regulated and combined by so
g the mind of the state and position of the muscles, that
may be definitely and aptly directed to them.

n this subject, an interesting discussion at a meeting of the Med-
gical Society: the Lancet, 1849, vol. i. p. 329.

...ence of one of the hemispheres disordered movements ensue. The a opposite to that on which the crus ce then roll over continuously and rep always round the long axis of their which the injury has been inflicted. take place with much rapidity; as often as sixty times in a minute, and may las movements have been observed in men, in whom there was an apoplectic effusion and by M. Belhomme, in a woman, in v on the left crus.[2] They may, perhaps, that the division or injury of the crus ce or imperfect and disordered movements, c body; the animal falls, and then, strugg side on the ground, and striving to rise wit over; and so, again and again, with the Such movements cease when the other c but probably only because the paralysis c almost complete.

STRUCTURE AND PHYSIOLOGY OF

The cerebrum is placed in connection w oblongata by its two *crura* or *peduncles:* cerebellum by the processes called superior processus a cerebello ad testes, and by the valve of Vieussens.

(the fourth ventricle) and a canal (the iter a tertio ad quartum ventriculum), which are the continuation of the canal that in the fœtus extended through the whole length of the spinal cord and brain. They may therefore be regarded as the continuation of the cerebro-spinal axis or column; on which, as a development from the simple type, the cerebellum is placed; and, on the further continuation of which, structures both larger and more numerous are raised, to form the cerebrum.

The crura cerebri are principally formed of nerve-fibres, of which the inferior are continuous with those of the anterior pyramidal and olivary tracts, and the superior with the round and posterior pyramidal tracts of the medulla oblongata. They may therefore be regarded as, principally, conducting organs: but each of them manifests also the character of a nervous centre, in that it contains a mass of vesicular substance, the *locus niger*, whose nerve-corpuscles abound in pigment-granules, and afford some of the best examples of the caudate structure. The office of the crura cerebri, as conductors, will appear in speaking of the relation of the cerebrum to voluntary motion, and the peculiar effects of their division: as centres, they are probably connected with the functions of the third nerve, which arises from their inner margins, and through which are directed the chief of the numerous and complicated movements of the eyeball and iris.

On their upper part the crura cerebri bear three pairs of small ganglia, or masses of mingled gray and white nerve-substance; namely, the *corpora geniculata externa* and *interna*, and the *corpora quadrigemina*, or *nates* and *testes*. Beneath or through the corpora quadrigemina pass the continuations of the round and posterior pyramidal tracts of the medulla oblongata, decussating as they proceed onwards: and nearer to the upper surface of the same ganglia pass the fibres of the superior crura of the cerebellum, mingling with the fibres that form the chief part of the origin of the optic nerves, with the functions of which nerves these ganglia appear intimately connected.

In its further course, each crus cerebri, enlarged by the addition of many fibres, forms, as it proceeds, a kind of *fibrous cone*, with its truncated apex in the pons. On it are placed in succession two other ganglia, the optic thalamus and corpus striatum, in which its fibres and those that are continually added to them, traverse variously-shaped masses and layers of gray substance, and from the anterior part of which, diverging in all directions and bending backwards, they pass into the substance of the corresponding cerebral hemisphere.

These several organs on each side of the cerebrum are connected by commissures, formed principally of nerve-fibres; namely, the corpora quadrigemina by part of the fibres of the round tract which

...ing beneath the convolutions fro
the median part of the fornix, connec
with the optic thalamus.

The cerebral convolutions appear to
plates of fibres, the ends of which are
of the brain, and are overlaid and mi
of gray nerve-substance. Some have s
fibres are connected in loops, of which
from the diverging fibres of the cone, a
the corpus callosum; but this is unce
matter is so arranged in layers that a ve
tion generally presents the appearance of
two intervening layers of white, substanc
external. In these gray layers, the outer
granular matter and nuclei, like those of
deeper layer are more perfectly formed cel

The *crura cerebri* appear as the princip
sions to and from the cerebrum, and divis
duces singular effects on the movements.
the animal moves round and round, rotati
from the injured towards the sound side,
lysis of the side opposite to the injury.
posed due to the interruption of the volu
cerebrum; for even though the cerebellun
combining the muscles whose co-operati
action, yet it is probable that the
proceed from the

the principal nervous centres for the sense of sight. The experiments of Flourens, Longet, and Hertwig, show that the removal of the corpora quadrigemina wholly destroys the power of seeing; and diseases in which they are disorganized are usually accompanied with blindness. Atrophy of them is also often a consequence of atrophy of the eyes.

Destruction of one of the corpora quadrigemina (or of one optic lobe in birds), produces blindness of the opposite eye. The loss of sight thus produced is not only because the corpora quadrigemina contain continuations of the optic tracts, or roots of the optic nerves, but because they are the organs in which the mind perceives the sensations of light. As Longet's experiments show, when the cerebral hemispheres of a pigeon are removed, and its optic thalami and optic lobes are left, it not only exhibits the reflex movements of the contraction of the iris and the closure of the eyelids when a candle is held to the eye, but when the candle is moved round before the eye, it moves its head after it, manifestly because it sees and watches it. It appears, indeed, not to see many things, and runs against obstacles; but this is because though it may see them it cannot recognize them, having lost all memory of objects through the loss of its cerebrum.

The loss of sight is the only apparent injury of sensibility sustained by the removal of the corpora quadrigemina. The removal of one of them affects the movements of the body, so that animals rotate, as after division of the crus cerebri, only more slowly: but this is probably due to giddiness and partial loss of sight. The more evident and direct influence is that produced on the iris. It contracts when the corpora quadrigemina are irritated: it is always dilated when they are removed; so that they may, perhaps, be regarded as the nervous centres governing its movements, and adapting them to the impressions derived from the retina through the optic nerves and tracts.

There is no evidence that the corpora quadrigemina are, in any sense, organs of the intellectual faculties, or of the affections. Yet it may be questioned if their connection with vision be their only function, seeing their large size in fish whose iris is not movable, and that generally neither their absolute nor their proportionate size in different animals bears any simple relation to the acuteness or extent of their several powers of vision.

The *optic thalami* probably participate in a small degree in the visual function of the corpora quadrigemina, for part of the fibres of the optic tract may be traced to their surfaces; and in a recent examination of the brain of a child born without eyes, the optic thalami as well as the corpora quadrigemina were found extremely small (cxc. 1851, p. 543). But the results of experiments prove

nothing on this point. They only show disturbances of the power of movement. Irritation of the optic thalami produces no convulsions, and only little pain (Longet and Flourens): destruction of one has effects very similar to those of division of one crus cerebri, namely, a rotation, in which the animal, remaining standing, turns continually round. Schiff, by whom a series of experiments on these various rotations has been made (clxii.), has shown that no such effect follows the removal of any other part of the brain; and Longet points out, as a strong contrast, that after removing all the cerebral hemispheres and the corpora striata, the animal can still stand and walk, but that, on removing one of the optic thalami, it falls down paralyzed on the opposite side, or commences the rotatory movement. The evidence [illegible] plexy and other diseases is similar: all such cases manifest a loss [illegible] f power of part or the whole of the opposite side of the body.

Concerning the function of the c[illegible]*ra striata*, experiments, and the effects of diseases, permit none [illegible] negative conclusions—such as that they are not the central or[illegible] for the sense of smell, nor peculiarly concerned in sensation [illegible] movement. The recent experiments of Schiff (clxii.) confirming [illegible] and, in many respects, correcting those of Magendie and othe[illegible], show that when they are removed in rabbits sensation is unimp[illegible]red, and the power of movement complete; so that although at first the creature remains at rest, it will after irritation, or spontaneously, in about half an hour begin to move, at first slowly, and then with increasing speed and larger leaps, till it strikes against some obstacle, when it falls, and again for a time remains torpid.

Various explanations are offered of these and other strange modes of movement which ensue when the several parts just considered are mutilated, such as that particular masses or tracts in the brain determine the impulses to move in this or that direction, and that, by destroying any part, the balance in which its impulse holds that of the corresponding part of the opposite side is lost. But no such explanations guide to the true physiology of these parts.

Taking together all the parts yet considered, *i. e.*, all the parts of the cerebro-spinal nervous system except the cerebral hemispheres, they appear to include the apparatus, 1st, for the direction and government of all the unfelt and involuntary movements of the parts which they supply; 2d, for the perception of sensations; and 3d, for the direction of such instinctive and habitual movements as do not require the exercise of judgment, deliberation, memory, or any other intellectual act. The medulla oblongata and spinal cord have their office in none but involuntary and unconscious movements; but above the medulla oblongata, the pons, and other organs, appear capable of such conditions as the mind may perceive; and of being, by the will, excited to the production of voluntary and

orderly movements. But these parts cannot be regarded as organs of the higher faculties of the mind: with them alone, an animal appears to possess neither memory of former sensations, nor judgment to determine and control its actions. Mere sensations, and will acting according to instinctive impulse and instinctive knowledge or habit, constitute the whole mind of the animal deprived of its cerebral hemispheres.

But seeing what manifestations of mind subsist in animals after the removal of the cerebral hemispheres, it is reasonable to suppose that these lower organs, the *cerebral* or *sensory ganglia*, naturally discharge the functions of which they then appear capable, and that the cerebral hemispheres are engaged in only the higher mental acts. This appears the more probable when it is considered that all the cerebral nerves are in direct connection with these ganglia; and are only through the medium of the highest of them, (including herein the olfactory ganglia as part of the brain) connected with the cerebral hemispheres; so that whatever acts are performed through these nerves, independently of the higher faculties of the mind, may be fairly ascribed to the power of these several ganglia. Again, the homologues of these organs, that is, of the corpora quadrigemina, the optic thalami, and corpora striata, and the olfactory lobes or ganglia, maintain, in the descending scale of the vertebrate animals a large size, and are proportionate to the development of their organs of sense; while the cerebral hemispheres regularly diminish in their proportion, till in the highest fish they are not larger than these ganglia, and in the lower fish are not larger than the optic or olfactory lobes alone. Now, in the same descending series, the intellectual powers seem to diminish commensurately with the decrease of the cerebral hemispheres; but there is no corresponding decrease of the lower powers of the mind, in the exercise of simple perception and will adapted to the instincts of which these ganglia at the base of the brain are supposed to be the organs.[1]

Neither perhaps can any such diminution be traced in those emotions and emotional acts, or expressions, which belong to the instincts that all animals appear to have in common, such as fear, anger, &c.; of these also it is not improbable that the cerebral ganglia may be the organs; but this can only be suspected while

[1] The whole of this subject is well discussed by Dr. Carpenter (cxxxi. p. 706, 5th Am. Ed), who regards the "series of ganglionic centres which have been enumerated as constituting the real *sensorium*; each ganglion having the power of communicating to the mind the impressions derived from the organ with which it is connected, and of exciting automatic muscular movements in respondence to these sensations:" and also regards "the ganglionic tract as the immediate centre of those movements which *directly* result from the excitement of the emotions."

...ormation thus determined by ...
...the organs by which the mind, 1st, ...
...impressions or sensations which it can ...
...by voluntary acts of will excit...
...voluntary determination; 3dly, ...
...it digests and reproduces them in sui...
...with, manifests itself in its higher a...
...and feelings, and in its faculties o...
...memory, reflection, induction, and im...
...faculties. The cerebral hemispheres ...
...in and through which the mind acts ...
...which have immediate relation to exter...
...thus we may be led without fear, wh...
...mind has other and higher parts or fa...
...may attain to the knowledge of things abov...
...ourselves and the spiritual world, which m...
...that through the senses, and exercised i...

The evidences that the cerebral hem...
...and degree in which above the organ...
...are: 1. That any severe injury of ...
...concussion, or sudden pressure by apopl...
...a man of all power of manifesting exte...
2. That in the same general proportio...
...mental faculties are developed in the ...
...man at different ages, the more are the ...
...spheres developed in comparison with th...
...system. 3. That no ... ...
...correspond ...

while we have regard only to the facts of science) is so sufficient as that which supposes an immaterial principle, not necessarily dependent for its existence on the brain, but incapable of external manifestation, or of knowledge of external things, except through the medium of the brain, and the nervous organs connected therewith. Such a principle would remain itself unchanged, in the case of injury or disease of the brain; but its external manifestations, and all its acts performed in connection with the brain, would be hindered or disturbed; as, for example, the work of any artist might be stopped or spoiled through deficiency or badness of his implements of art. And in the operations of such a principle, it might well be supposed that the power with which its several faculties are manifested would bear a direct proportion to the size of the organs through which they are manifested; for whether we suppose or not that the principle itself may, in different individuals, have different degrees of power, yet its power of manifestation or perception through the cerebral hemispheres, may vary as those organs do.

But while this may be true respecting those parts of the mind which have to do with the things of sense, it would require much more and different evidence and arguments to make it probable that the cerebral hemispheres, or any other parts of the brain, are in any meaning of the term, the *organs* of those parts or powers of the mind which are occupied with things above the senses. The reason or spirit of man, which has knowledge of divine truths, and the conscience, with its natural discernment of moral right and wrong, cannot be proved to have any connection with the brain. In the complex life we live, they are, indeed, often exercised in questions in which the intellect or some other lower mental faculty is also concerned; and in all such cases men's actions are determined as good or bad, according to the degree in which they are guided by the higher or by the lower faculties. But the reason and the conscience must be exercised independently of the brain, when they are engaged in the contemplation of things which have not been learned through the senses, or through any intellectual consideration of sensible things. All that a man feels in himself, and can observe in others, of the subjects in which his reason and his conscience are most naturally engaged; of the mode in which they are exercised, and the disturbance to which they are liable by the perception or ideas of sensible things; of the manner and sources of their instruction; of their natural superiority and supremacy over all the other faculties of the mind; and of his consciousness of responsibility for their use; all teaches him that these faculties are wholly different, not in degree only, nor as different members of one order, but in kind and very nature from all else of which he is composed; all, if rightly considered, must

incline him to receive and hold fast the clearer truth which Revelation has given of the nature and destinies of the spirit to which these, his highest faculties, belong.

Respecting the mode in which the mental principle operates in its connection with the brain there is no evidence whatever. But it appears that, for all but its highest intellectual acts, one of the cerebral hemispheres is sufficient. For numerous cases are recorded in which no mental defect was observed, although one cerebral hemisphere was so disorganized or atrophied, that it could not be supposed capable of discharging its functions. The remaining hemisphere was in thes e to the functions generally discharged by both; bu s not seem in any of these cases to have been ter h intellectual exercises; so that it is not certain th re will suffice for these. In general, the mind com sation, the impressions which it derives from one ob h hemispheres, and the ideas to which the two such rise are single; and in general, also, the mind rough both the hemispheres: its actions being, if , symmetrical as the hemispheres are. But i at when one hemisphere is disordered, the same object may produce two sensations, and suggest simultaneously different ideas: or, at the same time, two trains of thought may be carried on by the one mind acting, and being acted upon, differently in the two hemispheres. Thus are explicable some of the incoherences of dreaming and delirium; and, especially, those singular cases in which a person in delirium, puzzled by the two different, and seemingly simultaneous, trains of thought in which he is engaged, fancies himself two persons, and, as another, holds conversation with himself.[1]

In relation to common sensation and the effort of the will, the impressions to and from the hemispheres of the brain are carried across the middle line; so that, in destruction or compression of either hemisphere, whatever effects are produced in loss of sensation or voluntary motion, are observed on the side of the body opposite to that on which the brain is injured.

In speaking hitherto of the cerebral hemispheres as the organs of the mind, they have been regarded as if they were single organs, of which all parts are equally appropriate for the exercise of each of the mental faculties. But it is a more probable theory that each faculty has a special portion of the brain appropriated to it as its

[1] See Dr. Holland's essay on this subject (clxvii.); and Dr. Wigan's essay, and other works, on the Duality of the Mind, or, as it would be better called, of the Brain, for every reasonable person is as conscious of his unity as of his identity; indeed, the idea of personal identity involves that of unity.

proper organ. For this theory, the principal evidences among those collected by Drs. Gall and Spurzheim are as follows: 1. That it is in accordance with the physiology of the other compound organs or systems in the body, in which each part has its special function; as, for example, of the digestive system, in which the stomach, liver, and other organs perform each their separate share in the general process of digestion of the food. 2. That, in different individuals, the several mental functions are manifested in very different degrees. Even in early childhood, before education can be imagined to have exercised any influence on the mind, children exhibit various dispositions, each presents some predominant propensity, or evinces a singular aptness in some study or pursuit; and it is a matter of daily observation that every one has his peculiar talent or propensity. But it is difficult to imagine how this could be the case, if the manifestation of each faculty depended on the whole of the brain; different conditions of the whole mass might affect the mind generally, depressing or exalting all its functions in an equal degree, but could not permit one faculty to be strongly and another weakly manifested. 3. The plurality of organs in the brain is supported by the phenomena of some forms of mental derangement. It is not usual for all the mental faculties in an insane person to be equally disordered; it often happens that the strength of some is increased, while that of others is diminished; and in many cases one function only of the mind is deranged, while all the rest are performed in a natural manner. 4. The same opinion is supported by the fact that the several mental faculties are developed to their greatest strength at different periods of life, some being exercised with great energy in childhood, others only in adult age; and that, as their energy decreases in old age, there is not a gradual and equal diminution of power in all of them at once, but, on the contrary, a diminution in one or more, while others retain their full strength, or even increase in power. 5. The plurality of cerebral organs appears to be indicated by the phenomena of dreams, in which only a part of the mental faculties are at rest or asleep, while the others are awake, and, it is presumed, are exercised through the medium of the parts of the brain appropriated to them. 6. It is stated that the examination of the brains of individuals, each remarkable for some peculiar propensity or talent, has always demonstrated a corresponding development of a certain portion of the brain.

These facts have been so illustrated and adapted by phrenologists, that the theory of the plurality of organs in the cerebrum, thus made probable, has been commonly regarded as peculiar to phrenology, and as so essentially connected with it, that, if the system of Gall and Spurzheim be untrue, this theory cannot be maintained. But it is plain that all the system of phrenology built upon the theory may be false, and the theory itself true: for the school of

...ed on a true theory.
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that require separate organs, and w
subjects of which only the first or
attained. At any rate, the phrenol
could not be introduced here without
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Of the physiology of the other p
nothing can be said.

Of the offices of the *corpus callosum*, (l
and oblique commissure of the brain,
But instances in which it was absent, or
any evident mental defect, or with only a
coincident affections of other parts, mak
which is commonly assigned to it, of en
brain to act in concord, is exercised o
which the mind, acting on the brain, is
confirmed by the very late period of it
absence in all but the placental Mammal

To the fornix and other commissure
be assigned; but it is a reasonable hypot
actions of the parts between which th
(Fig. 75.)

As little is known of the functions o
glands. Indeed, Oesterlen raises the qu
structure or functions are those of ne
them among the glands with

its simplest form, may be regarded as a column or axis of nervous matter, extending from the olfactory bulbs on the ethmoid bone, to

Fig. 75.

This figure has been introduced with the view of assisting the student in his study of the relations of the inferior longitudinal commissure or *fornix*, which may be described as commencing in the centre of the thalamus nervi optici (L), proceeding from thence to the base of the brain, where it suddenly bends upwards and forwards, forming by this turn the knuckle (B), which is called corpus albicans or mammillare. This body receives a few fibres (A) from the locus niger (6) in the crus cerebri (5), running forward from thence towards the anterior commissure, receiving fibres from the convolutions at the base of the brain, crossing and as it were kneeling upon the anterior commissure (8), and ascending towards the great transverse commissure, forms the anterior pillar of the fornix (C), receiving fibres in its course from the under and front part of the anterior lobes, and thus forming the septum lucidum (D): running back from thence, passing in its course backwards over the thalamus nervi optici (L), it spreads laterally, constituting that portion which is called the body of the fornix (E): descending again at the back part of the brain it forms the descending or posterior pillar of the fornix *tænia hippocampi* (F), some of its fibres running back to be connected with the posterior lobes (I); others crossing the projection called hippocampus major (J), to be connected with the middle lobe, and others again passing over the pes hippocampi (H) to be connected with the anterior portion of the middle lobe. Thus does this commissure connect different portions of the convoluted surface of the brain together, which are inferior to the great transverse commissure, and on the same side of the mesial line. A. Fibres of the inferior longitudinal commissure, or fornix, from the locus niger. B. Corpus mammillare. C. Anterior pillars of inferior longitudinal commissure, or fornix. D. Septum lucidum. E. Body of the fornix, or centre of the commissure. F. Tænia hippocampi, or descending fibres of the inferior longitudinal commissure. G. Fibres covering the hippocampus major. H. Fibres covering the pes hippocampi. I. Fibres covering the hippocampus minor. K. Great transverse commissure divided in the mesial line. 8. Posterior cerebral ganglion, or thalamus. L. Anterior commissure. 5. Section of the crus cerebri. 6. Locus niger. 7. Anterior cerebral ganglion, or corpus striatum, partially scraped away.

the *filum terminale* of the spinal cord in the lumbar and sacral portion of the vertebral canal. The spinal nerves all present certain

... sense, it is not possible to d
ment in any besides the fifth or t
analogies to the spinal nerves, Sir
spinal nerve of the head.

According to their several function
may be thus arranged :—

Nerves of special sense .	Olfactory, o pharynge fifth.
" of common sensation	The greater the glosso-
" of motion . .	Third, fourt sixth, facia
Mixed nerves . . .	Pneumogastri

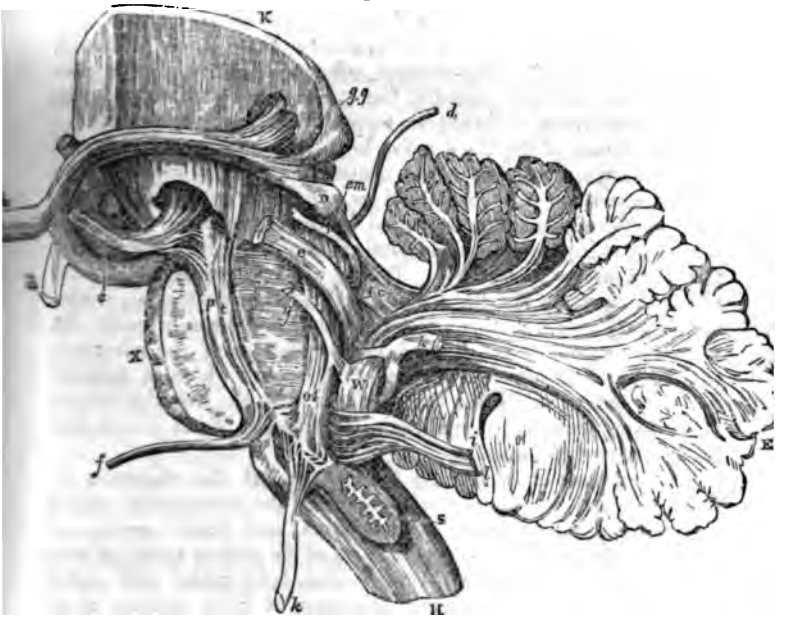
The physiology of the several nerves o
considered with the organs of those sens

Physiology of the Third, Fourth, and
Nerves.

The physiology of these nerves may be
because of their intimate connection with
of the muscles of the eyeball, which th
bably all formed exclusively of motor fib
when the trunk of the third nerve is ir
this may be because of some filaments o
backwards to the brain in the trunk of t
cent sensitive parts are involved in th

The third nerve ...

Fig. 76.



The drawing exhibits the cerebral connection of all the cerebral nerves except the 1st. It is from a sketch of Solly's, taken from two dissections of this part. D. Posterior optic tubercle. The generative bodies of the thalamus are just above it. E. Cerebellum. H. Spinal cord. I. Tuber cinereum. K. Optic thalamus divided perpendicularly. W. Corpus restiforme. X. Pons Varolii. *b b.* Optic nerves: this nerve is traced on the left side back beneath the optic thalamus and round the crus cerebri. It divides into four roots; the first (*g g*) plunges into the substance of the thalamus, the next runs over the external geniculate body and surface of the thalamus, the third goes to the anterior optic tubercle, the fourth runs to D, the testis or posterior optic tubercle. *c.* Third pair common oculo-muscular, arising by two roots like the spinal roots of the spinal nerves, the upper from the gray neurine of the locus niger, the lower from the continuation of the pyramidal columns in the crus cerebri and Pons Varolii, *p t.* *d.* Fourth pair, apparently arising from the inter-cerebral commissure (*tc*), but really plunging down to the olivary tract (*o t*) as it ascends to the optic tubercles. *e m.* Motor or non-ganglionic root of the fifth pair, arising from the posterior edge of the olivary tract. *e.* Sensory root of the fifth pair running down between the olivary tract and restiform body to the sensory tract. *f.* Sixth pair, or abducens, arising from the pyramidal tract. *g.* Seventh pair, facial nerve, or portio dura, arising by an anterior portion from the olivary tract and by a posterior portion from the cerebellic fibres of the anterior columns as they ascend on the corpus restiforme. W. *h.* Eighth pair, portio mollis, or auditory nerve, with its two roots embracing the restiform body. *i.* Ninth pair, or glosso-pharyngeal; and *j.* Tenth pair, or par vagum, plunging into the restiform ganglion. *s s.* Fibres of the optic nerve plunging into the thalamus; immediately below these letters is the corpus geniculatum externum. *k.* Eleventh pair, or lingual nerve; the olivary body has been nearly sliced off and turned out of its natural position; some of the filaments of the lingual nerve are traced into the deeper portion of the ganglion, which is left in its situation; others which are the highest are evidently connected *with the pyramidal tract.*

...on, which may be explained as
light on the retina being conveyed by
(probably to the corpora quadrigemina)
the third nerve to the iris. Hence
either the optic or the third nerve is d
the corpora quadrigemina are destroyed
when the optic nerve is divided, the co
excited by irritating that portion of th
with the brain; and when the third ne
of its distal portion will still excite cont
its fibres are distributed.

The contraction of the iris thus sho
reflex act, and in ordinary cases require
the optic nerve, corpora quadrigemina,
probably, also, seeing the peculiarities of
the ophthalmic ganglion. But, besides,
their pupils under the reflected stimulus
one retina or under irritation of one opti
rosis of one eye, its pupil may contract
posed to a stronger light: and generally
the pupils appears to be in direct proport
of light which stimulates either one or
one or both eyes are open.

The iris acts also in association with c
plied by the third nerve: thus, when the
or upwards and inwards, by the action
buted in the rectus internus and rectus
as if under direct

the admission of the largest number of rays, of which none are too divergent to be so refracted.[1]

The fourth nerve, or *Nervus trochlearis* or *patheticus*, (Fig. 76, D,) is exclusively motor, and supplies only the trochlearis or obliquus superior muscle of the eyeball. This muscle acts spasmodically when the nerve is irritated, and is paralyzed when the nerve is divided or otherwise hindered from its function. From this paralysis results a very slight, if any, deviation of the eye from its normal direction; the pupil is directed a very little upwards and outwards by the unbalanced action of the obliquus inferior, and a peculiar kind of double vision is produced in which the same object appears as two, placed one above the other, but again appears single when the head is inclined towards the shoulder of the opposite side to that on which the superior oblique is paralyzed (Szokalski; in Longet, cxxxvi. vol. ii. p. 398). These phenomena are explained by the peculiar actions of the oblique muscles, which, as Hunter[2] showed (i. vol. iv. p. 274), rotate the eye round its antero-posterior axis, or round such an imaginary line as would nearly correspond with the prolongation of the optic nerve. Thus, when the head is bent down for a certain distance towards either (say the left) shoulder, the corresponding points of the retinæ of both eyes may be held on a level horizontal line by the superior oblique of the right eye rotating the inner part of the eye downwards, and the inferior oblique of the left eye rotating the inner part of its eye upwards. Thus in health, the mind receives a similar and single impression from an object whether the head is erect or turned towards either side, through the action of the inferior oblique of one eye being associated with that of the superior oblique of the other. And thus in disease, when one superior oblique is paralyzed, the inner half of the retina of that eye is rotated upwards, and when the image of any object falls on it, the mind refers that object to a point lower than that to which it refers the image of the same object on the other retina, though all the inner parts of the latter retina are really lower than the corresponding points of the retina on the paralyzed side.

The sixth nerve, *Nervus abducens* or *ocularis externus*, (Fig. 76, F,) is also, like the fourth, exclusively motor, and supplies only the rectus externus muscle.[3] The rectus externus is, therefore, convulsed,

[1] On the contractions of the iris, and the functions of all its nerves, see Dr. Radclyffe Hall's essays (xciv. 1846).

[2] And more lately Hueck (clxvi.); Volkmann (xv. art. *Schen.*); and Dr. G. Johnson (lxxiii. art. *Orbit*).

[3] In several animals, it sends filaments to the iris (Radclyffe Hall); and it has probably done so in man, in some instances in which the iris has not

nerve within the cavity of the
used to be considered as giving
the import of these communicatio
subsequent distribution of its fil
nerve, are quite unknown: and th
the sixth nerve is, in function, m
sympathetic than any other cerebra

The question has often suggested
the eyeball should be supplied by th
them are within reach of the branche
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stance, within a small space, an exa
according to which, associate of antag
with motor nerves.

Now, in the several movements of th
to act with symmetrically placed mus
turned upwards or downwards, inwa
symmetrically placed muscles are suppli
i. e., with corresponding branches of t
sides; and the action of these symm
natural, as we have a natural tendency
of most parts. But, because of thi
movements of muscles supplied by sy
appear as if, when the two eyes are t
symmetrically, the muscles
plied with

oblique muscles: the simplest and easiest actions would be through branches of the corresponding nerves, acting similarly as symmetrical muscles; but the necessary movements of the two eyes require the contraction of the superior oblique of one side, to be associated with the contraction of the inferior oblique, and the relaxation of the superior oblique of the opposite side. For this, the fourth nerve of one side is made to act with a branch of the third nerve of the other side; as if, thus, the tendency to simultaneous action through the similar nerves of the two sides were prevented. At any rate, the rule of distribution of nerves here, seems to be, that when, in frequent and necessary movements, any muscle has to act with the antagonist of its fellow on the opposite side, it and its fellow's antagonist are supplied from different nerves.

Physiology of the Fifth or Trigeminal Nerve.

The fifth, trigeminal, or trifacial nerve, (Fig. 76, E,) resembles, as already stated, the spinal nerves, in that its branches are derived through two roots; namely, the *portio major*, the filaments of which expand to receive the corpuscles that form the Casserian ganglion, and the *portio minor*, which has no ganglion, and passes under the ganglion of the portio major to join the third branch or division which issues from it. The first and second divisions of the nerve, which arise wholly from the ganglion of the portio major, are purely sensitive. The third division, which is formed in part by the portio minor, and in part from the Casserian ganglion, is, in its trunk and many of its branches, both motor and sensitive.

Through the branches of the greater or ganglionic portion of the fifth nerve, all the anterior and antero-lateral parts of the face and head, with the exception of the skin of the parotid region (which derives branches from the cervical spinal nerves,) acquire common sensibility; and among these parts may be included the organs of special sense, from which common sensations are conveyed through the fifth nerve, and their peculiar sensations through their several nerves of special sense. All the muscles, also, acquire muscular sensibility through the filaments of the ganglionic portion of the fifth nerve distributed to them with their proper motor nerves.

Through branches of the lesser or non-ganglionic portion of the fifth the muscles of mastication, namely, the temporal masseter, two pterygoid, anterior part of the digastric, and mylo-hyoid, derive their motor nerves. The motor function of these branches is proved by the violent contraction of all the muscles of mastication in experimental irritation of the third, or inferior maxillary, division of the nerve; by paralysis of the same muscles when it is divided or disorganized, or from any reason deprived of power; and by the retention of the power of these muscles when all those supplied by

the facial nerve lose their power through paralysis of that nerve. The last instance proves best that, though the buccinator muscle gives passage to, and receives some filaments from, a buccal branch of the inferior division of the fifth nerve, yet it derives its motor power from the facial, for it is paralyzed together with the other muscles that are supplied by the facial, but retains its power when the other muscles of mastication are paralyzed. It is probable, therefore, that the buccal branch of the fifth contains only sensitive fibres; and that plied to the buccinator muscle, as to all the other sitive fibres are distributed to confer muscular

The sensitive ches of the greater division of the fifth nerve usual evidences, such as their distribution in p e and not capable of muscular contraction, the y of some of these parts, their loss of sensation paralyzed or divided, the pain without convulsion rbid or experimental irritation of the trunk or branches of the nerve, and the analogy of this portion of the fifth to the posterior root of a spinal nerve. (See Longet and others.

But although formed of sensitive filaments exclusively, the branches of the greater or ganglionic portion of the fifth nerve exercise a manifold influence on the movements of the muscles of the head and face and other parts in which they are distributed. They do so, in the first place, by providing the muscles themselves with that sensibility, without which the mind, being unconscious of their position and state, cannot voluntarily exercise them. It is probably, for conferring this sensibility on the muscles, that the branches of the fifth nerve anastomose so frequently with those of the facial and hypoglossal, and the nerves of the muscles of the eye; and it is because of the loss of this sensibility that when the fifth nerve is divided, animals are always slow and awkward in the movements of the muscles of the face and head, or hold them still, or guide their movements by the sight of the objects towards which they wish to move.

Again, the fifth nerve has an indirect influence on the muscular movements by conveying sensations of the state and position of the skin and other parts; which the mind perceiving is enabled to determine appropriate acts. Thus, when the fifth nerve, or its infra-orbital branch is divided, the movements of the lips in feeding must cease or be imperfect; a fact which led Sir Charles Bell into one of the very few errors of his physiology of the nerves. He supposed that the motion of the upper lip, in grasping food, depended directly on the infra-orbital nerve; for he found that after he had divided that nerve on both sides in an ass, it no longer seized the food with its lips, but merely pressed them against the ground, and

used the tongue for the prehension of the food. Mr. Mayo corrected this error. He found, indeed, that, after the infra-orbital nerve had been divided, the animal did not seize its food with the lip, and could not use it well during mastication, but that it could open the lips. He, therefore, justly attributed the phenomena in Sir C. Bell's experiments to the loss of sensation in the lips; the animal not being able to feel the food, and, therefore, although it had the power to seize it, not knowing how or where to use that power.

Lastly, the fifth nerve has an intimate connection with muscular movement through the many reflex acts of muscles of which it is the necessary excitant. Hence, when it is divided, and can no longer convey impressions to the nervous centres to be thence reflected, the irritation of the conjunctiva produces no closure of the eye, the mechanical irritation of the nose excites no sneezing, that of the tongue no flowing of saliva; and although tears and saliva may flow naturally, their efflux is not increased by the mechanical or chemical or other stimuli, to the indirect or reflected influence of which it is liable in the perfect state of this nerve.

The fifth nerve, through its ciliary branches and the branch which forms the long root of the ciliary or ophthalmic ganglion, exercises, also, some influence on the movements of the iris. When the trunk or the ophthalmic portion is divided, the pupil becomes, according to Valentin (iv. vol. ii. p. 666), contracted in men and rabbits, and dilated in cats and dogs; but, in all cases, becomes immovable, even under all the varieties of the stimulus of light. How the fifth nerve thus effects the iris is unexplained; according to Longet, the same effects are produced by destruction of the superior cervical ganglion of the sympathetic, so that possibly they are due to the injury of those filaments of the sympathetic which, after joining the trunk of the fifth at and beyond the Casserian ganglion, proceed with the branches of its ophthalmic division to the iris: or, as Dr. R. Hall ingeniously suggests, the influence of the fifth nerve on the movements of the iris may be ascribed to the affection of vision in consequence of the disturbed circulation or nutrition in the retina, when the normal influence of the fifth nerve and ciliary ganglion is disturbed. In such disturbance, increased circulation making the retina more irritable might induce extreme contraction of the iris; or, under moderate stimulus of light, producing partial blindness, might induce dilatation; but it does not appear why, if this be the true explanation, the iris should in either case be immovable and unaffected by the various degrees of light.

Furthermore, the complete paralysis or division of the fifth nerve, by the morbid effects which it produces in the organs of special sense, makes it probable that, in the normal state, the fifth nerve exercises some direct influence on all these organs or their func-

cal irritation in the nose), may be i
impaired; so may the hearing; an
nerve is paralyzed, the tongue lose
rior and lateral parts, *i. e.*, in the
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distributed.

The loss of the sense of taste may
of the fifth nerve being, really, a ner
be because it supplies, in the anterior a
a necessary condition for the proper
deferring this question till the gloss
considered, it may be observed that in s
paralysis, or division, of the fifth nerve
of the special senses may be lost; the
sensibility to common impressions, f
directly on the fifth nerve, but also the
peculiar impressions for the reception an
are purposely constructed and supplied
the fifth. The facts observed in these
explained by the influence which the f
nutritive processes in the organs of the
unreasonable to believe that, in paraly
tissues may be the seats of such change
the vascular congestion, œdema, and oth
the face and other tegumentary parts
paralysis; and that these changes, whic
when they affect external part
ment of str

influence on nutrition were conveyed through the filaments
ympathetic, which join the branches of the fifth nerve at
nd the Casserian ganglion, rather than through the fila-
f the fifth itself; and this is confirmed by some experiments
extirpation of the superior cervical ganglion of the sym-
appeared to produce the same destructive disease of the
ommonly follows the division of the fifth nerve.
yet, that the filaments of the fifth nerve, as well as those of
pathetic, may conduct such influence appears certain from
s, including that by Mr. Stanley, in which the source of
lysis of the fifth nerve was near the brain, or at its very
efore it receives any communication from the sympathetic
The problem, therefore, cannot yet be certainly solved.
stence of ganglia of the sympathetic in connection with all
cipal divisions of the fifth nerve where it gives off those
which supply the organs of special sense—for example,
nection of the ophthalmic ganglion with the ophthalmic
the origin of the ciliary nerves; of the sphenopalatine
with the superior maxillary division where it gives its
s to the nose and the palate; of the otic ganglion with the
maxillary near the giving off of filaments to the internal
d of the submaxillary ganglion with the lingual branch of
—all these connections suggest that a peculiar and probably
influence of the sympathetic and fifth nerves is exercised
utrition of the organs of the special senses; and the results
iment and disease confirm this by showing that the nutrition
gans may be impaired in consequence of impairment of the
f either of the nerves.
gular connection between the fifth nerve and the sense of
shown in cases of no unfrequent occurrence, in which blows
injuries implicating the frontal nerve as it passes over the
e followed by total blindness in the corresponding eye.
idness appears to be the consequence of defective nutrition
etina; for although, in some cases, it has ensued immedi-
if from concussion of the retina, yet in some it has come
ually, like slowly progressive amaurosis, and in some with
atory disorganization, followed by atrophy of the whole eye.[1]
ain, the fifth nerve is shown intimately connected with the
cases in which paralysis of the third has followed neural-
e fifth; and not less, by the influence of belladonna applied
laments of the fifth, and producing a kind of paralysis of
through a reflected narcotizing influence on the branches of
l.

[1] a case is recorded by Snabilie in the Nederland-ch Lancet, August,

Physiology of the Facial Nerve.

The facial, or *portio dura* of the seventh pair of nerves, (Fig. 76, *g*,) is the motor nerve of all the muscles of the face, including the platysma, but n[illegible] (including any of the muscles of mastication already enumerated (p. 348); it supplies, also, through the connection of its trunk with the Vidian nerve, by the petrosal nerves, some of the muscles, most prob[illegible]ati and azygos uvulæ, of the soft palate; by its tym[illegible] it supplies the stapedius and laxator tympani, and th[illegible]anglion the tensor tympani; through the *chorda tym*[illegible] the lingualis and some other muscular fibres of the [illegible] branches given off before it comes upon the face, i.[illegible]uscles of the external ear, the posterior part of t[illegible]nd the stylo-hyoideus.[1]

To all these muscle[illegible]tor nerve, and it is probably exclusively motor in i[illegible]in is produced by irritating it near its origin (Valu[illegible]ndications of pain which are elicited when any of its branches are irritated may be explained by the abundant anastomoses which, in all parts of its course, it forms with sensitive nerves, whose filaments being mingled with its own are the true source of the pain. Such anastomoses are effected with the fifth nerve through the petrosal branches of the Vidian, and probably also through the chorda tympani, and with the pneumogastric nerve through its auricular branch, even before the facial leaves the cranium.

When the facial nerve is divided, or in any other way paralyzed, the loss of power in the muscles which it supplies, while proving the nature and extent of its functions, displays also the necessity of its perfection for the perfect exercise of all the organs of the special senses. Thus, in paralysis of the facial nerve, the orbicularis palpebrarum being powerless, the eye remains open through the unbalanced action of the levator palpebræ, and the conjunctiva, thus continually exposed to the air and the contact of dust, is liable to repeated inflammation, which may end in thickening and opacity of both its own tissue and that of the cornea. These changes, however, ensue much more slowly than those which follow paralysis of the fifth nerve, and never bear the same destructive character; both because the nutrition of the eye is not directly interfered with, and because the globe can still be moved upwards and inwards, so as to carry the cornea partially under the angle of the upper eyelid in winking and sleeping. In paralysis of the facial nerve, also, tears are apt to flow constantly over the face, apparently because of the paralysis of the tensor tarsi muscle, and the loss of

[1] On the minute anatomy of the facial nerve, see especially Morganti (cxx. 1845, or an abstract in xxv. 1844–5, p. 53); and Beck (clxiv.).

the proper direction and form of the orifice of the puncta lacrymalia. By these things the sense of sight is impaired.

The sense of hearing, also, is impaired in many cases of paralysis of the facial nerve; not only in such as are instances of simultaneous disease in the auditory nerves, but in such as may be explained by the loss of power in the muscles of the internal ear. The sense of smell is commonly, at the same time, impaired through the inability to draw air briskly towards the upper part of the nasal cavities, in which part alone, the olfactory nerve is distributed; because, to draw the air perfectly in this direction, the action of the dilators and compressors of the nostrils should be perfect.

Lastly, the sense of taste is impaired, or may be wholly lost in paralysis of the facial nerve, provided the source of the paralysis be in some part of the nerve, between its origin, and the giving off of the chorda tympani. This result, which has been observed in many instances of disease of the facial nerve in man,[1] appears explicable only by the influence which, through the chorda tympani, it exercises on the movements of the lingualis and the adjacent muscular fibres of the tongue; and, according to some, or probably in some animals, on the movements of the stylo-glossus. This result is not due to any gustatory fibres conveyed by the chorda tympani from the Vidian nerve to the tongue; for the loss of taste is observed when the facial nerve is paralyzed by some affection behind the junction of the great petrosal branch of the Vidian, when, therefore, whatever filaments of the Vidian there may be in the chorda tympani, are unaffected. We can, therefore, only suppose that the accurate movement of these muscles of the tongue is essential to the exercise of taste; a fact, if it be so, which is the more singular, because the sense of taste is not materially impaired in cases of paralysis of all the other muscles of the tongue, through injury of the hypoglossal nerve.

Together with these effects of paralysis of the facial nerve, the muscles of the face being all powerless, the countenance acquires on the paralyzed side a characteristic, vacant look, from the absence of all expression: the angle of the mouth is lower, and the paralyzed half of the mouth looks longer than that on the other side; the eye has an unmeaning stare. All these peculiarities increase, the longer the paralysis lasts; and their appearance is exaggerated, when, at any time, the muscles of the opposite side of the face are made active in any expression, or in any of their ordinary functions. In an attempt to blow or whistle, one side of the mouth

[1] See especially C. Bernard (cxxii. 1844). See also Guarini (cxx. 1842), and Verga (xc. 1843; and for evidences against this view, see Morganti (cxx. 1845 and 1846). He maintains that the chorda tympani is formed exclusively of sensitive fibres; but in this, he is most probably wrong.

and cheek acts properly, but the other side is motionless, or flaps loosely at the impulse of the expired air; so, in trying to suck, one side only of the mouth acts; in feeling, the lip and cheek are powerless, and food lodges between the cheek and gum.

The number of movements concerned in respiration, which are performed under the control of the facial nerve, and the great share which it has in the movements most expressive of the states of the mind, led Sir Charles Bell to place the facial in his class of respiratory nerves. [illegible] instances in which, when unable to act unde[illegible], or in other functions, the facial nerve has yet [illegible] action in respiratory movements; its paralysis, [illegible]s so in respect to every function alike. As a r[illegible], it must not be considered independent of the [illegible] which it forms so numerous anastomoses; for a[illegible]ugh the facial nerve alone that all the mu[illegible]put into their naturally expressive actions, [illegible]the mind has of suppressing, controlling, and imitating, or acting all these expressions, can only be exercised by voluntary and well-educated actions, directed through the facial nerve with the guidance of the knowledge of the state and position of every muscle; which knowledge is acquired only through the fifth nerve, which confers sensibility on the muscles, and appears, for this purpose, to be more abundantly supplied to the muscles of the face, than any other sensitive nerve is to those of other parts.

It has been already said, that the facial nerve perhaps supplies the levator palati and azygos uvulæ muscles with motor power; but the same is also ascribed, as probable, to the pneumogastric and accessory nerves. The evidence for the facial is, chiefly, the fact that when it is paralyzed the uvula often deviates to the opposite side, and recovers its median position when the paralysis ceases; a condition which is also said to be sometimes observed when the petrosal nerves, through which alone the facial can supply the palate, are injured in fracture of the base of the skull. The middle posterior palatine nerve, also, passes into the levator palati and azygos uvulæ, and may, through the petrosal nerves and spheno-palatine ganglion, receive filaments from the facial nerve. But, on the other hand, irritation of the trunk of the facial nerve produces no contractions of these muscles of the palate (Hein, lxxx. 1844; Valentin, iii.); and the experiments of Hein seemed to show that such contractions did follow the irritation of the pneumogastric and accessory nerves, from one or both of which filaments pass to the palate through branches of the glosso-pharyngeal.[1]

[1] The several cases relating to this question are given in xxv. 1843–5.

Physiology of the Glosso-Pharyngeal Nerve.

The glosso-pharyngeal nerves, in the enumeration of (Fig. 76, *i*,) he cerebral nerves by numbers according to the position in which hey leave the cranium, are considered as divisions of the *eighth pair f nerves*, in which term are included with them the pneumogastric nd accessory nerves. But the union of the nerves under one term inconvenient, although in some parts the glosso-pharyngeal and neumogastric are so combined in their distribution that it is im-ssible to separate them in either anatomy or physiology.

The glosso-pharyngeal nerve appears to give filaments through s tympanic branch (Jacobson's nerve), to the fenestra ovalis, and nestra rotunda, and the Eustachian tube; also, to the carotid exus, and, through the lesser petrosal nerve, to the spheno-pala-ne ganglion.[1] After communicating, either within or without the anium, with the pneumogastric, and, soon after it leaves the anium, with the sympathetic, digastric branch of the facial, and e accessory nerve, the glosso-pharyngeal nerve parts into the two incipal divisions indicated by its name, and supplies the mucous embrane of the posterior and lateral walls of the upper part of e pharynx, the Eustachian tube, the arches of the palate, the onsils and their mucous membrane, and the tongue as far forwards the foramen cæcum in the middle line, and to near the tip at the les and inferior part.

Some experiments make it probable that the glosso-pharyngeal erve contains, even at its origin, some motor fibres, together with ose of common sensation and the sense of taste. For Volkmann xxx. 1840), and Hein (lxxx. 1844), when they divided the nerve ithin the skull, and then irritated its distal portion, saw move-ents of the pharynx and of the palate and its arches, which peared to be due to contractions of the stylo-pharyngeus, and, rhaps, also, of the palato-glossus muscles. And the recent ex-eriments of Biffi and Morganti (lxxx. 1847, p. 360), confirm these, though the former ones (cxx. 1847) did not. Whatever motor fluence, therefore, is conveyed directly through branches of the osso-pharyngeal may be ascribed to the filaments of the pneumo-stric or accessory that are mingled with it.

The experiments of Dr. John Reid (xciv. 1838), confirming ose of Panizza and Longet, tend to the same conclusions; and eir results probably express nearly all the truth regarding the rt of the glosso-pharyngeal which is distributed to the pharynx. hese results were that: 1. Pain was produced when the nerve, rticularly its pharyngeal branches, were irritated. 2. Irritation the nerve before the giving off its pharyngeal branches, or of

[1] See especially Beck (clxiv.).

any of these branches, gave rise to extensive muscular motions
the throat and lower part of face: but, when the nerve was divid
these motions were excited by irritating the upper or cranial porti
while irritation of the lower end, or that in connection with
muscles, was followed by no movement; so that these moti
must have depended on a reflex influence transmitted to the mus
through other nerves by the intervention of the nervous cent
3. When the functions of the brain and medulla oblongata w
arrested by poison with prussic acid, irritation
the glosso-pha it was joined by any branc
from the pneu no movements in the muscle
the pharynx o h it was distributed; while
irritating the phar the pneumogastric, or the gl
pharyngeal nerv red the communicating bran
just alluded to. s of all the pharyngeal mus
and of the upp agus followed.
The most p erefore, may be that what m
influence the glosso-pharyngeal nerve may seem to exercise, is
either to the filaments of the pneumogastric or accessory that
mingled with it, or to impressions conveyed through it to
medulla oblongata, and thence reflected to muscles through m
nerves, especially the pneumogastric, accessory, and facial. T
the glosso-pharyngeal nerve excites through the medium of
medulla oblongata the actions of the muscles of deglutition.
the chief centripetal nerve engaged in these actions; yet not
only one, for, as Dr. John Reid has shown, the acts are scar
disturbed or retarded when both the glosso-pharyngeal nerves
divided.

But besides being thus a nerve of common sensation in the p
which it supplies, and a centripetal nerve through which impress
are conveyed to be reflected to the adjacent muscles, the gl
pharyngeal is also a nerve of special sensation; being the gusta
nerve, or nerve of taste in all the parts of the tongue to which
distributed. After many discussions, the question, which is
nerve of taste?—the lingual branch of the fifth, or the gl
pharyngeal?—may be most probably answered by stating that
are both nerves of this special function. For very nume
experiments and cases have shown that when the trunk of the
nerve or its lingual branch is paralyzed or divided, the sens
taste is completely lost in the superior surface of the anterior
lateral parts of the tongue. The loss is instantaneous after divi
of the nerve; and, therefore, cannot be ascribed to the defe
nutrition of the part, though to this, perhaps, may be ascribed
more complete and general loss of the sense of taste when the w
of the fifth nerve has been long paralyzed.

But, on the other hand, while the loss of taste in the part of

tongue to which the lingual branch of the fifth nerve is distributed proves that to be a gustatory nerve, the fact that the sense of taste is at the same time retained in the posterior and postero-lateral parts of the tongue, and in the soft palate and its anterior arch, to which (and to some parts of which exclusively) the glosso-pharyngeal is distributed, proves that this also must be a gustatory nerve. In a patient lately in St. Bartholomew's Hospital, the left lingual branch of the fifth nerve was divided in removing a portion of the lower jaw: she lost both common sensation and the sensation of taste in the tip and anterior parts of the left half of the tongue, but retained both in all the rest of the tongue. M. Lisfranc and others have noted similar cases; and the phenomena in them are so simple and clear, that there can scarcely be any fallacy in the conclusion that the lingual branches of both the fifth and the glosso-pharyngeal nerves are gustatory nerves in the parts of the tongue which they severally supply.

This conclusion is confirmed by some experiments on animals;[1] and, perhaps, more satisfactorily as concerns the sense of taste in man, by observation of the parts of the tongue and fauces in which the sense is most acute. According to Valentin's experiments made on thirty students, the parts of the tongue from which the clearest sensations of taste are derived, are the base, as far as the foramen cæcum and lines diverging forwards on each side from it; the posterior palatine arches down to the epiglottis; the tonsils and upper part of the pharynx over the root of the tongue. These are the seats of the distribution of the glosso-pharyngeal nerve. The anterior dorsal surface, and parts of the anterior and inferior parts of the tongue, in which the lingual branch of the fifth is alone distributed, conveyed no sense of taste in the majority of the subjects of Valentin's experiments; but even if this were generally the case, it would not invalidate the conclusion that, in those who have the sense of taste in the anterior and upper part of the tongue, the lingual branch of the fifth is the nerve by which it is exercised. And the same may be said of the soft palate and uvula; in those who have the sense of taste in these parts its nerves must be branches of the fifth; for, unless it be through the minute branch which passes into the Jacobsonian plexus, and might thence pass through the inferior petrosal nerve and spheno-palatine ganglion, the glosso-pharyngeal nerve can send no filaments to the soft palate.

[1] Namely, those of Magendie, Mayo, Müller, and Kornfeld (see Müller xxxii. p. 776, Am. Ed.); and most completely by those of Dr. Alcock (lxxi. 1836), and of Morganti and Biffi (cxx. 1847). On the contrary are the experiments of Panizza (recorded by Dr. Burrows, lxxi. vol. xvi.); of Valentin (iii. and iv.), and of Wagner (xxxviii. No. 75). Some explanation of the probable source of the contradiction is given by Morganti (*l. c.*).

Physiology of the Pneumogastric Nerve.

The *pneumogastric nerve, nervus vagus, or par vagum*, (Fig. 70, *i*,) has, of all the cranial and spinal nerves, the most various distribution, and influences the most various functions, either through its own filaments or those which, derived from other nerves, are mingled in its branches.

The parts supplied [illegible] of the pneumogastric nerve are as follows: by its [illegible]ches, which enter the pharyngeal plexus, a l[illegible]e mucous membrane, and, probably, all the mu[illegible]nx; by the superior laryngeal nerve, the muc[illegible]he under surface of the epiglottis, the glottis, [illegible] of the larynx, and the crico-thyroid muscle; by [illegible]al nerve, the mucous membrane and muscula[illegible]ches, the lower part of the pharynx and larynx [illegible]es of the larynx except the crico-thyroid; by œsophageal branches, the mucous membrane and muscular coats of the œsophagus. Moreover, the branches of the pneumogastric nerve form a large portion of the supply of nerves to the heart and the great arteries through the cardiac nerves, derived from both the trunk and the recurrent nerve; to the lungs, through both the anterior and the posterior pulmonary plexuses; and to the stomach by its terminal branches passing over the walls of that organ.

From the parts thus enumerated as receiving nerves from the pneumogastric, it might be assumed that it is a nerve of mixed function, both sensitive and motor. Experiments prove that it is so from its origin, for the irritation of its roots, even within the cranial cavity, produces both pain and convulsive movements of the larynx and pharynx, and when it is divided within the skull the same movements follow the irritation of the distal portion, showing that they are not due to reflex action. Similar experiments prove that, through its whole course, it contains both sensitive and motor fibres, but after it has emerged from the skull, and, in some instances even sooner, it enters into so many anastomoses that it is hard to say whether the filaments it contains are, from their origin, its own, or whether they are derived from other nerves combining with it. This is particularly the case with the filaments of the sympathetic nerve, which are abundantly added to nearly all the branches of the pneumogastric. The likeness to the sympathetic which it thus acquires, is further increased by its containing many filaments derived, not from the brain, but from its own petrosal ganglia, in which filaments originate, in the same manner as in the ganglia of the sympathetic, so abundantly that the trunk of the nerve is visibly larger below the ganglia than above them (Bidder and Volkmann, xv. article *Nervenphysiologie*). Next to

the sympathetic nerve, that which most importantly communicates with the pneumogastric is the accessory nerve, whose internal branch joins its trunk, and is lost in it.

Properly, therefore, the pneumogastric might be regarded as a triple-mixed nerve; having, out of its own sources, motor, sensitive, and sympathetic or ganglionic nerve-fibres; and to this natural complexity it adds that which it derives from the reception of filaments from the sympathetic, accessory, and cervical nerves, and, probably, the glosso-pharyngeal and facial.

The most probable account of the particular functions which the branches of the pneumogastric nerve discharge in the several parts to which they are distributed may be drawn from Dr. John Reid's experiments on dogs (xciv. vols. xlix. and li.). They show that —1. The pharyngeal branch is the principal, if not the sole, motor nerve of the pharynx and soft palate,[1] and is most probably wholly motor, a part of its motor fibres being derived from the internal branch of the accessory nerve. 2. The inferior laryngeal nerve is the motor nerve of the larynx, irritation of it producing vigorous movements of the arytenoid cartilages; while irritation of the superior laryngeal nerve gives rise to no action in any of the muscles attached to the arytenoid cartilages, but merely to contractions of the crico-thyroid muscle. 3. The superior laryngeal nerve is chiefly sensitive; the inferior, for the most part, motor; for division of the recurrent nerves puts an end to the motions of the glottis, but without lessening the sensibility of the mucous membrane; and division of the superior laryngeal nerves leaves the movements of the glottis unaffected, but deprives it of its sensibility. 4. The motions of the œsophagus are dependent on motor fibres of the pneumogastric, and are probably excited by impressions made upon sensitive fibres of the same; for irritation of its trunk excites motions of the œsophagus, which extend over the cardiac portion of the stomach; and division of the trunk paralyzes the œsophagus, which then becomes distended with the food. 5. The cardiac branches of the pneumogastric nerve are one, but not the sole channel through which the influence of the central organs and of mental emotions is transmitted to the heart. 6. The pulmonary branches form the principal, but not the only channel by which the impressions on the mucous surface of the lungs that excite respiration are transmitted to the medulla oblongata. Dr. Reid was unable to determine whether they contain motor fibres; but reasons for believing that they do so have been already given (p. 131).

From these results, and referring to what has been said in former

[1] On the probable influence of the facial in the movements of the palate, see p. 354; and on the glosso-pharyngeal, see p. 355.

chapters, the share which the pneumogastric nerve takes in the functions of the several parts to which it sends branches may be understood :—

1. In deglutition, the motions of the pharynx are of the reflex kind. The stimulus of the food, or other substance to be swallowed, acting on the filaments of the glosso-pharyngeal, the filaments of the superior laryngeal given to the pharynx, and the cervical nerves, is conducted to the medulla oblongata, where it is reflected, chiefly, through the pneumoga[illegible]uscles of the pharynx, and, perhaps, also of the so[illegible]rther, pp. 164 and 323).

2. In the function[illegible]e sensitive filaments of the pneumogastric supply[illegible]ility by which the glottis is guarded against the [illegible]n bodies, or of irrespirable gases. The contact [illegible]s the filaments of the superior laryngeal branc[illegible]astric; and the impression conveyed to the med[illegible]ether it produces sensation or not, is reflected [illegible]f the recurrent or inferior laryngeal branch, and excites contraction of the muscles that close the glottis. Both these branches of the pneumogastric co-operate also in the production and regulation of the voice; the inferior laryngeal determining the contraction of the muscles that vary the tension of the vocal cords, and the superior laryngeal conveying to the mind the sensations of the state of these muscles necessary for their continuous guidance. And both the branches co-operate in the actions of the larynx, in the ordinary slight dilatation and contraction of the glottis in the acts of expiration and inspiration, and more evidently in those of coughing and other forcible respiratory movements (p. 142).

3. It is partly through their influence on the sensibility and muscular movements in the larynx, that the pneumogastric nerves exercise so great an influence on the respiratory process, and that the division of both the nerves is commonly fatal. To determine how death is in these cases produced has been the object of innumerable and often contradictory experiments. It is probably produced differently in different cases, and in many is the result of several co-operating causes. Thus, after division of both the nerves, the respiration at once becomes slower, the number of respirations in a given time being commonly diminished to one-half (Emmert, xxxii. p. 371; J. Reid, xciv. 1839); probably, because the pneumogastric nerves are the principal conductors of the impression of the necessity of breathing to the medulla oblongata. Respiration does not cease, for it is probable that the impression may be conveyed to the medulla oblongata, through the sensitive nerves of all parts in which the imperfectly aerated blood flows (see p. 182); yet the respiration being retarded, adds to the other injurious effects of division of the nerves.

Again, division of both pneumogastric trunks, or of both their recurrent branches, is often very quickly fatal in young animals; but in old animals, the division of the recurrent nerves is not generally fatal, and that of both the pneumogastric trunks is not always fatal (J. Reid, *l. c.*), and, when it is so, the death ensues slowly. This difference is, probably, because the yielding of the cartilages of the larynx in young animals permits the glottis to be closed by the atmospheric pressure in inspiration, and they are thus quickly suffocated, unless tracheotomy is performed (Legallois, cxxxix). In old animals, the rigidity and prominence of the arytenoid cartilages prevent the glottis from being completely closed by the atmospheric pressure; even when all the muscles are paralyzed, a portion at its posterior part remains open, and through this the animal continues to breathe. Yet, the diminution of the orifice for respiration, may add to the difficulty of maintaining life.

In the cases of slower death, after division of both the pneumogastric nerves, the lungs are commonly found gorged with blood, œdematous, or nearly solid, or with a kind of low pneumonia, and with their bronchial tubes full of frothy, bloody fluid and mucus, changes to which, in general, the death may be proximately ascribed. These changes are due, perhaps, in part, to the influence which the pneumogastric nerves exercise on the chemical process of respiration in the lungs, and the movements of the air-cells and bronchi; yet, since they are not always produced in one lung when its pneumogastric nerve is divided, they cannot be ascribed wholly to the suspension of organic nervous influence (J. Reid). Rather, they may be ascribed to the hindrance to the passage of blood through the lungs in consequence of the diminished supply of air, and the excess of carbonic acid in the air-cells (see p. 144): and in part, also, as the experiments of Traube especially show (clxxi. 1846), they appear due to the passage of food, and of the various secretions of the mouth and fauces through the glottis, which, being deprived of its sensibility, is no longer stimulated or closed in consequence of their contact. He says, that if the trachea be divided and separated from the œsophagus, or if only the œsophagus be tied, so that no food or secretion from above can pass down the trachea, no degeneration of the tissue of the lungs will follow the division of the pneumogastric nerves. So that, on the whole, death after division of the pneumogastric nerves may be ascribed, when it occurs quickly in young animals, to suffocation through mechanical closure of the paralyzed glottis: and, when it occurs more slowly, to the congestion and pneumonia produced by the diminished supply of air, and by the passage of foreign fluids into the bronchi, and aggravated by the diminished frequency of respiration, the insensibility to the diseased state of the lungs, the diminished aper-

ture of the g ttis, and the loss of the due nervous influence upon the process o espiration.

4. Respec g the influence of the pneumogastric nerves on the movements o the œsophagus and stomach, the secretion of gastric fluid, the sensation of hunger, absorption from the stomach, and the action of the heart, former pages may be referred to, especially pages 89, 164, 181 to 184, and 323. On all these parts the influence is, as its structure (p. 358) would suggest, like that of the sympathetic more than that of the cerebro-spinal nerve; the movements that follow its irritation being in the stomach slow and continuous, and in the h rdily following the irritation.

Physiolo essory Nerve.

In the preceding pas that all the motor influence which the pneum ise, is conveyed through fila- ments, which, fro to them: and this is perhaps true. Yet a quesu rtained, which has been often discussed, whether t of the motor filaments that appear to belong nerves are not given to them from the access

The principal ry nerve, its external branch, supplies the sterno-mastoid and trapezius muscles; and, though pain is produced by irritating it, is composed almost exclusively of motor fibres. It might appear very probable, therefore, that the internal branch, which is added to the trunk of the pneumogastric just before the giving off of the pharyngeal branch, is also motor; and that through it the pneumogastric nerve derives part of the motor fibres which it supplies to the muscles enumerated above. And, further, since the pneumogastric nerve has a ganglion just above the part at which the internal branch of the accessory nerve joins its trunk, a close analogy may seem to exist between these two nerves and the spinal nerves with their anterior and posterior roots. In this view, Arnold and several later physiologists have regarded the accessory nerve as constituting a motor root of the vagus nerve; and, although this view cannot now be maintained, yet it is very probable that the accessory nerve gives some motor filaments to the pneumogastric. For, among the experiments on the point, many have shown that when the accessory nerve is irritated within the skull, convulsive movements ensue in some of the muscles of the larynx; all of which, as already stated, are supplied, apparently, by branches of the pneumogastric: and (which is a very significant fact) Vrolik states that in the chimpansé the internal branch of the accessory does not join the pneumogastric at all, but goes direct to the larynx. On the whole, therefore, although in

[1] An abstract of nearly the whole discussion is given in xxv. 1843–4.

some of the experiments no movements in the larynx followed irritation of the accessory nerve, yet it may be concluded that it gives to the pneumogastric nerve some of the motor filaments which pass, with the laryngeal branches, to the muscles of the larynx, especially to the crico-thyroid (Bernard, cxii. 1844).

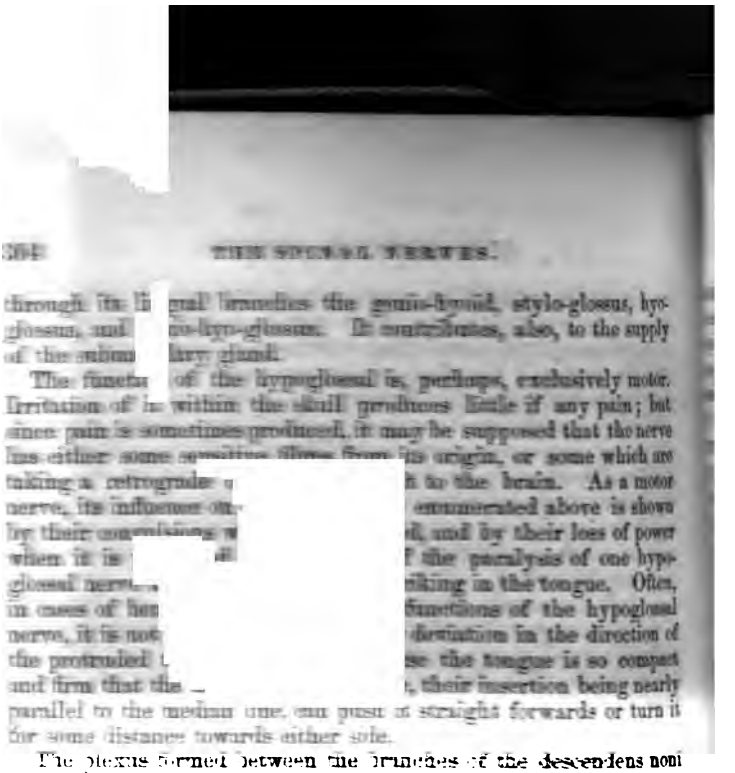
It is not certain whether, besides these, the accessory gives to the pneumogastric any other motor filaments; for the experiments to determine whether, on irritating the accessory within the skull the muscles of the pharynx, œsophagus, or other parts besides the larynx are convulsed, are completely contradictory, and there appears no other means than that of experiment by which the difficulty may be solved. It is, however, certain that the accessory nerve does not supply *all* the motor filaments which the branches of the pneumogastric contain; for division of the pneumogastric produces a much more extensive paralysis of motion in all the parts that it supplies than division of the accessory or its internal branch does: especially in regard to the larynx, and other respiratory organs, almost the only effects of destruction of the accessory are loss of voice, and panting in great efforts (Bernard, cxxii. 1844).

Among the roots of the accessory nerve the lower, arising from the spinal cord, appear to be composed exclusively of motor fibres, and to be destined entirely to the trapezius and sterno-mastoid muscles: the upper fibres, arising from the medulla oblongata, contain many sensitive as well as motor fibres, and these alone are included in the internal branch, which joins the pneumogastric (Bernard, Morganti). Of these, indeed, it is not rare to find some that are united with the pneumogastric at its ganglion, or even within the cranial cavity; and of these upper roots also, the communicating branch is formed, which sometimes takes the place of the posterior root of the first cervical nerve.

As a respiratory nerve, under the influence of the medulla oblongata, the accessory has been often observed to conduct impressions exciting movements necessary to respiration in the sterno-mastoid and trapezius muscles, after these muscles have ceased to move under the influence of the will. They may thus act whenever any of the parts of the brain above the medulla oblongata cease to be capable of conveying impressions; for then the will cannot act on these or any other muscles, though they are still amenable to the reflex influence of the medulla oblongata.

Physiology of the Hypoglossal Nerve.

The hypoglossal, or ninth nerve, or *motor linguæ*, (Fig. 76, *k*,) has a peculiar relation to the muscles connected with the hyoid bone, including those of the tongue. It supplies through its descending branch (*descendens noni*), the sterno-hyoid, sterno-thyroid, and omo-hyoid; through a special branch the thyro-hyoid, and



through its li gual branches the genio-hyoid, stylo-glossus, hyo-glossus, and no-hyo-glossus. It contributes, also, to the supply of the subma lary gland.

The functi of the hypoglossal is, perhaps, exclusively motor. Irritation of it within the skull produces little if any pain; but since pain is sometimes produced, it may be supposed that the nerve has either some sensitive fibres from its origin, or some which are taking a retrograde c it to the brain. As a motor nerve, its influence on enumerated above is shown by their convulsing w il, and by their loss of power when it is f the paralysis of one hypo-glossal nerve, ilking in the tongue. Often, in cases of hen functions of the hypoglossal nerve, it is not deviation in the direction of the protruded t se the tongue is so compact and firm that the , their insertion being nearly parallel to the median one, can push it straight forwards or turn it for some distance towards either side.

The plexus formed between the branches of the descendens noni and those of the second and third cervical nerves, serves not only to distribute filaments of the hypoglossal to the depressor muscles of the hyoid bone, but to admit into the descendens noni filaments of the cervical nerves which take a recurrent course through it, and of which some return to the medulla oblongata through the trunk of the hypoglossal, and others go to the tongue through its lingual branches (Volkmann, lxxx. 1840). Hence, and from other connections with the cervical nerves higher up, the hypoglossal nerve has ample borrowed sensibility.

Physiology of the Spinal Nerves.

Little need be added to what is already said of these nerves (pp. 305 and 306). Magendie and Bernard alone dissent from the opinion that the anterior roots of the spinal nerves are formed exclusively of motor fibres. They hold that certain sensitive fibres, after traversing the posterior roots and ganglia, assume a recurrent course through the anterior roots, and thus give them a slight degree of sensibility, which is lost when the posterior roots are divided, but which is clearly indicated by signs of pain when the anterior roots, or those portions of them that are connected with the ganglia, are irritated. Longet, who formerly claimed this discovery, now denies the experiments; perhaps rightly; yet such a retrogression of sensitive fibres through motor roots has a parallel in the instance of the descendens noni just referred to; and its existence in the spinal nerves would not invalidate the propriety of the general statement, that the anterior roots of the nerves are

exclusively motor roots, for those recurrent fibres have no relation to the spinal nerves beyond the ganglia.

Beyond the ganglia all the spinal nerves appear to be mixed nerves, and to contain as well sympathetic filaments, as those of sensation and motion derived through their own roots.

Of the functions of the ganglia of the spinal nerves nothing is known. That they are not the reflectors of any of the ascertained reflex actions through the spinal nerves, is shown by the reflex movements ceasing when the posterior roots are divided between the ganglia and the spinal cord.

PHYSIOLOGY OF THE SYMPATHETIC NERVE.

The sympathetic nerve, or sympathetic system of nerves, obtained its name from the opinion that it is the means through which are effected the several sympathies in morbid action which distant organs manifest. It has also been called *trisplanchnic* nerve, because it is principally distributed among the organs of the three chief visceral systems, the thoracic, abdominal, and pelvic; and the *nervous system of organic life*, in the supposition that it alone, as a nervous system, influences the organic processes. All the terms are defective: for, there is sufficient reason to believe that the cerebro-spinal nervous system may influence the organic functions: the cerebro-spinal system is not excluded from the viscera, nor the trisplanchnic nerve excluded from other parts: the cerebro-spinal system is the medium of numerous sympathies, and the blood of as many or more. But, since the title *sympathetic nerve* has the advantage of long and most general custom in its favor, and is not more inaccurate than the others, it will be here employed.[1]

The general differences between the fibres of the cerebro-spinal and sympathetic nerves are already stated (p. 283); and it has been said that although such general differences exist, and are sufficiently discernible in selected filaments of each system of nerves, yet they are neither so constant, nor of such a kind, as to warrant the supposition, that the different modes of action of the two systems can be referred to the different structures of their fibres. Rather, it is probable, that the laws of conduction by the fibres are in both systems the same, and that the differences manifest in the modes of action of the systems are due to the multiplication and separation of the nervous centres of the sympathetic: ganglia, or nervous

[1] The title "ganglionic system of nerves," would be in every respect preferable, if it were sure that the ganglia on the spinal nerves give origin to no nerve-filaments but such as are attached to the rest of the ganglionic system, and that no nerve-filaments attached to this system are derived from the brain and spinal cord.

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ably the ganglia on the glosso-pharyn
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fibres appear to originate, which, in s
from the proper ganglia of the symp
the same parts. To the second divisi
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connecting cords, which make up wh
the trunks of the sympathetic nerve;
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viscera. Of the former, the number
generally to the vertebræ; of the latte
viscera.

The structure of all these ganglia ap
lar; all containing, 1st, nerve-fibres tr
fibres originating in them; 3dly, nerve-c
origin to these fibres; and 4thly, other
And in the trunk, and thence proceed
thetic, there appear to be always, 1st,
ganglia; 2dly, fibres derived from the
spinal nerves; 3dly, fibres transmitted
cord through the roots of their nerves

Respecting the course of the sy
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nerves: connected with the brain and the rest of the sympathetic system, by the branches of the third, fifth, and sympathetic nerves, that form its roots; yet, by filaments of its own, controlling, in some mode and degree, the processes in the interior of the eye.

Of the fibres that arise in the spinal ganglia some appear to pass into the posterior branches of the spinal nerves, and to be distributed with them; the rest pass through the branches by which the spinal nerves communicate with the trunks of the sympathetic, and then entering the sympathetic are distributed with its branches to the viscera. With these, also, a certain number of the large, ordinary cerebro-spinal nerve-fibres, after traversing the ganglia, pass into the sympathetic.

Of the fibres derived from the ganglia of the sympathetic itself, some go straightway towards the viscera, the rest pass through the branches of communication between the sympathetic and the anterior branches of the spinal nerves, and, joining these spinal nerves, proceed with them to their respective seats of distribution, especially to the more sensitive parts.

Thus through these communicating branches, which have been generally called roots or origins of the sympathetic nerve, an interchange is effected between all the spinal nerves and the sympathetic trunks; all the ganglia, also, which are seated on the cerebral nerves, have roots (as they are called) through which filaments of the cerebral nerves are added to their own. So that, probably, all sympathetic nerves contain some intermingled cerebral or spinal nerve-fibres; and all cerebral and spinal nerves some filaments derived from the sympathetic system or from ganglia. But the proportions in which these filaments are mingled are not uniform. The nerves of voluntary muscles contain in their trunks a majority of large or cerebro-spinal nerve-fibres, but in their peripheral distribution either only, or a majority of, fine fibres, of which, however, the greater part are of course the cerebro-spinal fibres reduced in size. The nerves of the skin, and of most sensitive mucous membranes, contain, for the most part, equal numbers of both large and fine fibres, but the proportions often deviate in both directions; and in all, in their peripheral distribution, the fine fibres greatly preponderate. In the nerves of involuntary muscles, and in those of the less sensitive mucous membrane, there is a great predominance of the fine filaments.[1]

The physiology of the sympathetic nerve is so obscure, except when illustrated by that of the cerebro-spinal system, that it will

[1] The account given above is derived almost entirely from Kölliker (cxiv. and xv. 1844–5): the other principal writings relating to the minute anatomy of the sympathetic nerve are those of Hannover (cxix.); Bidder and Volkmann (cxxvi.); Wagner (cxv.); Remak (clxxii.); Todd and Bowman (xxxix.).

be advisable to consider its mode of action in the same manner as that in which the functions of the latter system were described.

And first, it may be stated generally as nearly certain, that the sympathetic nerve-fibres are simple conductors of impressions, as those of the cerebro-spinal system are, and that the ganglionic centres have (each in its appropriate sphere) the like powers both of collecting and of communicating impressions. Their power of collecting im[illegible]tly proved in ordinary dis-eases, as when exp[illegible]ally unfelt, gives rise to sen-sations of pain, or [illegible]ommonly subject to mental influence is evid[illegible]actions by the various con-ditions of the m[illegible] cases impressions must be conducted to and [illegible]e distance between the part and the spinal c[illegible]so, in experiments, now more than sufficient[illegible]s of the semilunar ganglia, the splanchnic [illegible]opatic, and other ganglia and nerves, have ofte[illegible]n, and have excited move-ments in the muscular organs supplied from the irritated part.[1]

In the case of pain excited, or movements affected by the mind, it [illegible] that the conduction of impressions is effected through the cerebro-spinal fibres which are mingled in all, or most all, parts of the sympathetic nerves. There are no means of knowing this; but it may be assumed that the conduction is effected through the cerebro-spinal nerve-fibres then, whether or not they were uninterruptedly between the brain or spinal cord and the part affected, it must be assumed that their mode of conduction is modified by the ganglia. For if such cerebro-spinal fibres conducted in the ordinary manner, the parts should be always sensible and liable to the influence of the will, and impressions should be conveyed to and fro instantaneously. But this is not the case: on the contrary, through the branches of the sympathetic nerve and its ganglia pain, or morbid impressions, or impressions exaggerated by the morbid sensibility of the nerves or ganglia, can be conveyed.

Either, therefore, the nerve-fibres conduct differently in the sympathetic nerves from what is ordinary, or else the ganglia have a power of modifying the method of conduction of impressions. It is as if the facility with which an impression may be communicated from one fibre to another in the ganglia were such, that the whole force of ordinary impressions in the nerve-fibres is lost in diffusion among the rest of their contents. This seems not improbable; for some cases show that when fibres certainly belonging to cerebro-

[1] See especially Longet, cxxxvi.; Valentin (iv. vol. ii. p. 107, &c.); Rodrigue Hall, xciv. July, 1846. The last-named observer says, that movements most constantly and actively ensue when the whiter parts of ganglia are irritated; and that they often fail of being produced when the ganglia irritated are gray and pellucid.

spinal nerves pass through ganglia of, or connected with, the sympathetic, they do not so rapidly, or so surely, transmit impressions as when they have no such relation to the ganglia. Thus, the iris is not under the direct or perfect influence of the will; though the passage of filaments of the third nerve to it is shown by its acting with the muscles supplied by the same nerve. Neither does it always contract when the third nerve is irritated, and when all the other muscles supplied by the same nerve are put in action. So, also, when all the other muscles supplied by the facial nerve contract on irritating its trunk, the levator palati and azygos uvulæ, to which its filaments probably pass through the spheno-palatine ganglion, do not contract.

We may explain these facts by believing that the impression, whether of the mind, or of artificial irritation, which would be conveyed at once through nerve-fibres unconnected with ganglia, is, in the ganglia of the sympathetic, communicated and diffused among the corpuscles and the other fibres; and thus, as one may say, is exhausted without reaching the muscles, or, in the case of a centripetal nerve, the spinal cord or brain.

Whether, then, the conduction be effected through proper sympathetic nerve-fibres, or through cerebro-spinal fibres mingled with them and traversing their ganglia, there is this peculiarity to be ascribed either to the fibres or, more probably, to the ganglia—that the conduction is effected more slowly; so that when, for example, a ganglion on a sympathetic nerve is irritated, the movements in the parts supplied from it do not immediately ensue, and pain is not indicated till after repeated irritations, or till, by exposure or otherwise, the fibres and ganglia have become morbidly irritable. But, with this exception, it is probable that the laws of conduction of impressions are the same in both cerebro-spinal and sympathetic systems.

Respecting the general action of the ganglia of the sympathetic nerve little need be said here, since they were taken as examples by which to illustrate the common modes of action of all nervous centres (see p. 298). Indeed, complex as the sympathetic system, taken as a whole, is, it presents in each of its parts a simplicity not to be found in the cerebro-spinal system; for each ganglion with afferent and efferent nerves forms a simple nervous system, and might serve for the illustration of all the nervous actions with which the mind is unconnected. But it will be more convenient to consider the ganglia now in connection with the functions that they may be supposed to control, in the several organs supplied by the sympathetic system alone, or in conjunction with the cerebro-spinal.

The general processes which the sympathetic appears to influence are those of involuntary motion, secretion, and nutrition.

Many movements take place involuntarily in parts supplied with cerebro-spinal nerves, as the respiratory and other spinal reflex motions; but the parts principally supplied with sympathetic nerves are usually capable of none but involuntary movements, and when the mind acts on them at all, it is only through the strong excitement or depressing influ[illegible]ssion, or through some voluntary movement with w[illegible] of the involuntary part are commonly associated. [illegible]nach, and intestines are examples of these state[illegible] heart and stomach, though supplied in large measu[illegible]eumogastric nerves, yet probably derive through t[illegible]s except such as have arisen from their ganglia, and[illegible]f the nature of sympathetic fibres.

The parts which are [illegible] motor power by the sympathetic nerve continue [illegible]h more feebly than before, when they are separated from their natural connections with the rest of the sympathetic system, and wholly removed from the body. Thus, the heart, after it is taken from the body, continues to beat in Mammalia for one or two minutes, in reptiles and Amphibia for hours; and the peristaltic motions of the intestines continue under the same circumstances. Hence the motion of the parts supplied with nerves from the sympathetic are shown to be, in a measure, independent of the brain and spinal cord. Their movements, too, though accelerated, or at last retarded and enfeebled, remain, even after their removal from the body, like those which are natural to them, retaining their character of adaptation to a purpose, and often their harmony and rhythm. They are in all these respects different from the quiverings and twitchings of muscles supplied with cerebro-spinal nerves, when they are similarly separated from the body. The same difference continues when the muscles, having ceased to act spontaneously, are stimulated to fresh contractions by mechanical or other irritation. Of a muscle supplied with cerebro-spinal nerves, only that fasciculus acts to which the stimulus is applied; it instantly twitches once or twice in a disorderly ineffective manner, and then lies at rest again. But of one supplied from the sympathetic nerve, the contraction commences more slowly but continues longer; it is a more deliberate and more orderly contraction, more like the natural action of the muscle during life, and extending often far beyond the part to which the irritation was first applied. The difference is well shown (as will be mentioned in the chapter on MOTION) with the electro-galvanic stimulus, and affords a nearly constant and characteristic distinction between the muscles severally supplied by the two nervous systems, and distin-

guished in their structure by their simple, or their transversely-striated, fibres.

The difference here indicated must, probably, be ascribed to the influence of the ganglia of the sympathetic, which combine for regular and harmonious action the several fasciculi that act in the manner just described. It cannot be ascribed to the nerve-fibres, for all the parts are supplied with a mixture of both cerebro-spinal and ganglionic fibres; and it can hardly be supposed that a peculiar mode of action of the latter could quite counterbalance the tendency to the ordinary action of the former. Neither can the peculiarity be ascribed to the muscular fibres; for the heart has fibres like those of voluntary muscle, yet they act, in this respect, like those of the other muscles supplied with sympathetic nerves and controlled by ganglia.

Among the ganglia, to which this co-ordination of movements is to be ascribed, must be reckoned, not those alone which are on the principal trunks and branches of the sympathetic external to any organ, but those also which lie in the very substance of the organs; such as those discovered in the heart by Remak, others like to which have been found also in the mesentery close by the intestines, in the kidneys, and other parts. The extension of discoveries of such ganglia will probably diminish yet further the number of instances in which the involuntary movements appear to be effected independently of central nervous influence.

It seems to be a general rule, at least in animals that have both cerebro-spinal and sympathetic nerves much developed, that the involuntary movements excited by stimuli conveyed through ganglia are orderly and like natural movements, while those excited through nerves without ganglia are convulsive and disorderly; and the probability is, that, in the natural state, it is through the same ganglia that natural stimuli, impressing centripetal nerves, are reflected through centrifugal nerves to the involuntary muscles. As the muscles of respiration are maintained in uniform rhythmic action by the reflecting and combining power of the medulla oblongata, so, probably, are those of the heart, stomach, and intestines, by their several ganglia. And as with the ganglia of the sympathetic and their nerves, so with the medulla oblongata and its nerves distributed to respiratory muscles—if these nerves or the medulla oblongata itself be directly stimulated, the movements that follow are convulsive and disorderly; but if the medulla be stimulated through a centripetal nerve, as when cold is applied to the skin, then the impressions are reflected so as to produce movements which, though they may be very quick and almost convulsive, are yet combined in the plan of the proper respiratory acts.

Such, then, seems to be the peculiarity of the action of the sympathetic nerve, and especially of its ganglia, in determining the

involuntary movements of the parts that it supplies. And, as first stated, this peculiarity seems to be due not to an essentially different mode of action in either the fibres or the ganglia of the sympathetic, but to the arrangement of those ganglia, which are inserted in or very near to the parts whose movements they control.

Respecting the influence of the sympathetic nerve in nutrition and secretion, we [illegible] chapters on those processes (pages 234, 235, and [illegible]de in which the influence is exercised is unknov[illegible]known whether it be exercised through symp[illegible]spinal fibres, or both. The apparent distribution o[illegible]f fibres to all sensitive and secreting parts, and the [illegible]of isolating them, make the difficulty of deciding th[illegible]nsuperable. The difficulty is much greater in the [illegible]the lower Vertebrata; for it would appear that in t[illegible]on as the centres of the cerebro-spinal system are develop[illegible], so is its connection with the processes of organic life more intimate. In frogs, for instance, all the organic functions may be carried on for several days after the removal of the brain and spinal cord, saving only the medulla oblongata for the maintenance of respiration; but in Mammalia, and most of all, in man, even a slight injury of either brain or spinal cord may disturb all the organic functions. The regular movements of the stomach and intestines, the heart, and urinary bladder, independently of the spinal cord or brain, is manifested by numerous experiments in reptiles and Amphibia; but in Mammalia, the separation of these organs from the spinal cord or brain is sufficient to render their actions feeble and irregular, or, after a time, to stop them altogether.

Probably, therefore, the safest view of the question is to regard all the processes of organic life in man as liable to the combined influences of the cerebro-spinal and the sympathetic systems; to consider that those influences may be so combined as that the sympathetic nerves and ganglia may be in man, as in the lower animals, the parts through which the ordinary and constant influence of the nervous force is exercised on the organic processes; while the cerebro-spinal nervous centres and their ganglia are the parts from which the proper sympathetic ganglia derive supplies of nervous force, and from which, more often or more regularly than in the lower animals, the processes of the organic and the animal life are made to work in connection and mutual adaptation.

Finally, in regard to the exercise of nervous influence upon the organic processes, it appears proper to consider it as exercised not only through the medium of the circulation, but also more directly; and as affecting, for instance, the organic chemical affinities of the molecules engaged in them. It is true that the varying conditions

nervous force affect the contractions of the muscular coats of teries, as they do those of other involuntary muscles; but es in the mode of nutrition and secretion in a part cannot be ned by mere variations in the diameter of its bloodvessels, or quantity of blood supplied to it. Daily observation shows in form results in secretion and nutrition in cases of disease, of all have, for a common condition, the enlargement of the vessels of the diseased part; something, therefore, besides the ement of the bloodvessels must, in these cases, determine the nt events; and so, when the various exercise of nervous ce in a part affects the size of its vessels and the supply of this change cannot be considered as the only source of the e in its mode of secretion or nutrition.

CHAPTER XVI.

CAUSES AND PHENOMENA OF MOTION.

e vital motions of the solid parts of animals present two pal kinds, differing in the organs of their production, in their mena, and in their causes: they are first, the oscillatory n or vibration of microscopic cilia with which the surfaces tain membranes are beset; and secondly, the motion from ction of fibres, which either have a longitudinal direction and ed at both extremities, or form circular bands: the contrac- r shortening of the fibres bringing the fixed parts nearer to other. This latter kind of motion is generally effected by n of muscular fibres; but in some few instances by fibres ng from the muscular in structure and chemical properties, esembling in all respects, except in their capacity of motion, bres of ordinary fibro-cellular tissue.

CILIARY MOTION.

just said, this consists in the incessant vibration of fine, pel- blunt processes, about 1-5000th of an inch long, termed cilia, ed on the free extremities of the cells of epithelium cover- rtain surfaces of the body. The form of epithelium on which ccur is most commonly of the cylindrical kind (Figs. 77, 78; so p. 246); but sometimes, as on the surface lining the cere- entricles, it is of the tessellated variety (p. 246).

Man, and probably in Mammalia generally, the ciliary epithe-

lium lines the interior of the nasal cavity, except the olfactory region (Todd and Bowman, xxxix. vol. ii. p. 5), and of the frontal

Fig. 77.

Fig. 78.

Fig. 77. Vibratile or ciliated epithelium: *a*, nucleated cells, resting on their smaller extremities; *b*, cilia.

Fig. 78. *a*, *b*, *c*, *d*, *e*, *f*. Nucleated ciliary cells: their free ends straight, and furnished with filaments called cilia, of different shapes; *a*, nucleus, *d*, cilia.

and other sinuses communicating with it, the lachrymal canal and sac, and is spread over the mucous surface of both eyelids, but not over the conjunctiva covering the eye itself. From the posterior part of the nasal cavity, it passes to the upper part of the pharynx, which it lines to about opposite the lower border of the atlas: it is also spread over the upper surface of the soft palate, and laterally is continued to the orifice of the Eustachian tube, through which canal it extends into the cavity and membrane of the tympanum. Ciliary epithelium occurs also over the whole extent of the respiratory mucous tract, commencing at the larynx, and ceasing only near the terminations of the bronchi (p. 123). It is met with also in the female generative apparatus, commencing about the neck of the uterus, extending along the Fallopian tubes to their fimbriated extremities, and continued for a short distance along the peritoneal surface of the tubes; and in the male, it occurs in the epididymis (Hassall). In Mammalia, there is no instance of its occupying any part of the urinary mucous surface; but in reptiles it lines the urinary tubules to a greater or less extent, and sometimes, though not generally, proceeds within the Malpighian capsules (Bowman, xliii. 1842; Valentin, xxxiv. bd. viii. p. 92; Kölliker, lxxx. 1845, p. 519).

If a portion of ciliary mucous membrane from a living or recently dead animal be moistened, and examined with a microscope, the cilia are observed to be in constant motion, either whirling round their fixed extremities so that their ends describe circles, or waving continually backwards and forwards, and alternately rising and

falling with a lashing or fanning movement. During the lashing movements, each of the cilia performs a motion somewhat similar to that performed during the feathering of an oar in rowing (Quekett, lxxi. May, 1844): hence the general result of their movement is to produce a continuous current in a determinate direction; and this direction is invariably the same on the same surface, being usually towards its external orifice. In the production of such current probably consists the principal use of the cilia, which are thus enabled to propel the fluids or minute particles which come within the range of their influence, and to aid in their expulsion from the body. In the Fallopian tube, the direction of the current excited by the cilia is towards the cavity of the uterus, and may thus be of service in aiding the passage of the ovum. Of the purposes served by the cilia covering the surface of the cerebral ventricles nothing is known.

The nature of the ciliary motion, and the cause on which it depends, are equally obscure. It seems to be alike independent of the will, of the direct influence of the nervous system, and of muscular contraction; for it is involuntary, there is no nervous or muscular tissue in the immediate neighborhood of the cilia, and it continues for several hours after death or removal from the body, provided the portion of examined tissue is kept moist. Its independence of the nervous system is shown, also, in its occurrence in the lowest invertebrated animals apparently unprovided with anything analogous to a nervous system; in its persistence in animals killed by prussic acid, narcotic or other poisons, and after the direct application of narcotics to the ciliary surface, or the discharge of a Leyden jar, or of a galvanic shock through it. In their rhythmic action, and its persistence after death or removal from the body, the ciliary movements bear a close analogy to those of the heart: and the analogy is made closer by both kinds of movements being diminished by cold and increased by heat.[1]

MUSCULAR AND THE ALLIED MOTIONS.

As already observed, the contractile tissues by which motion is effected are of two kinds, viz., contractile fibro-cellular tissue, and muscular tissue.

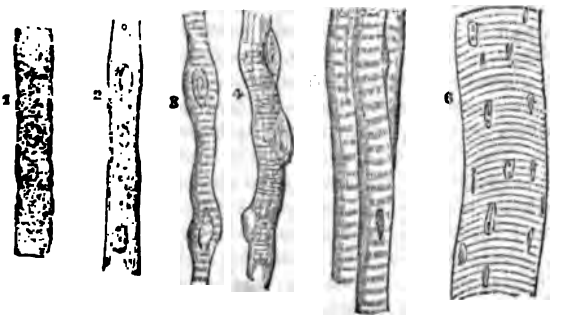
The *contractile fibro-cellular tissue* differs in no respect, except in its power of contraction, from ordinary fibro-cellular tissue. It enters largely into the composition of the tunica dartos, and is the principal cause of the wrinkling and contraction of the scrotum on exposure to cold: the fibres of the cremaster assist in some measure in producing this effect, but are chiefly concerned in drawing up

[1] For the best accounts of Cilia, see Dr. Sharpey (lxxiii. art. *Cilia*), and Henle (xxxvii.).

e *muscles of animal life*, or *striped muscles*, include the whole of voluntary muscles, the heart, the muscular tissue of the nx and upper part of the œsophagus, the lymphatic hearts of and reptiles, and the stomach and intestines of some fish. oluntary muscles are composed of fleshy bundles inclosed in ings of fibro-cellular tissue, by which each is at once connected and isolated from, those adjacent to it. Each bundle is again d into smaller ones, similarly ensheathed and similarly divi- ; and so on, through an uncertain number of gradations, till, eyond the reach of the unaided eye, one arrives at the *primi- asciculi*, or the *muscular fibres*, peculiarly so called.

e *primitive fasciculi* consist of tubes of delicate structureless rane, the *sarcolemma* of Mr. Bowman, inclosing a number of nts. They are cylindriform or prismatic, with five or more according to the manner in which they are compressed by ent fasciculi. Their breadth varies in different animals, from h to 1-500th of an inch; in man, from 1-200th to 1-500th, verage of the majority being about 1-400th. Their most

Fig. 79.



of the development of striped muscular fibre.
rangement of the primitive cells in a linear series.—After Schwann.
cells united. The nuclei separated, and some broken up; longitudinal lines becom- arent.—From a fœtal calf three inches long.
Transverse stripes apparent. In 3, the nuclei are internal, and bulge the fibre. In are prominent on the surface.—From a fœtal calf of two months old.
nsverse stripes, fully formed and dark; nuclei disappearing from view.—From the infant at birth.
mentary fibre from the adult, treated with acid; showing the nuclei.—Magnified 00 diameters.

ng, though not constant characteristics are their pale yellow and their being apparently marked by striæ, which pass ersely around them, in slightly curved or wavy parallel lines,

... by transverse impressions distance apart as the striæ on the it is generally concluded that the tive fasciculi is produced by the the transverse marks on all those same levels (Fig. 70).

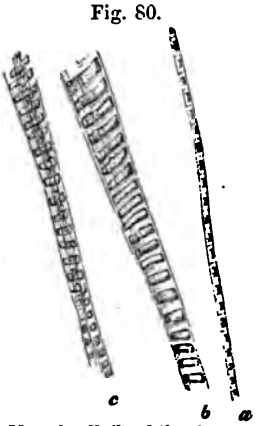
Each primitive fasciculus contai tive fibrils; and when fully forme sarcolemma with the exception o seem occupied with a glutinous pell ture fasciculi that there is an appea is filled either with fluid or with mi

At present, there is much questi fibrils, and of the source of their s verse impressions. Some deny the exist except when the muscle is contracted tion after death; while others belie corpuscles, or discs, connected by a stance. The transverse marks on the on the fasciculus, correspond to the s most recent view on the subject is taneously by Dr. Sharpey (cxlix.) an ing to which the alternate dark and fibril is composed, have each a quad tangular form. Every bright partic its centre by a fine, dark, transverse space is divided into two equal par border may be perceived

Properties of Muscular Tissue.

The property of muscular tissue, by which its peculiar functions are exercised, is its contractility, through which the contraction or shortening of muscles is excited by all kinds of stimuli, applied either directly to the muscles, or indirectly to them through the medium of their motor nerves. This property, although commonly brought into action through the nervous system, appears to be inherent in the muscular tissue, and not derived by it from the nerves (see p. 35). For 1st, it may be manifested in a muscle which is isolated from the influence of the nervous system by division of the nerves supplying it, so long as the natural tissue of the muscle is duly maintained by nutrition; 2dly, it is manifest in a portion of muscle, in which, under the microscope, no nerve-fibre can be traced; and 3dly, it is retained in all the muscles when it may be supposed that the function of their nerves is suspended by the inhalation of ether or of chloroform (Harless, lxxx. 1847).

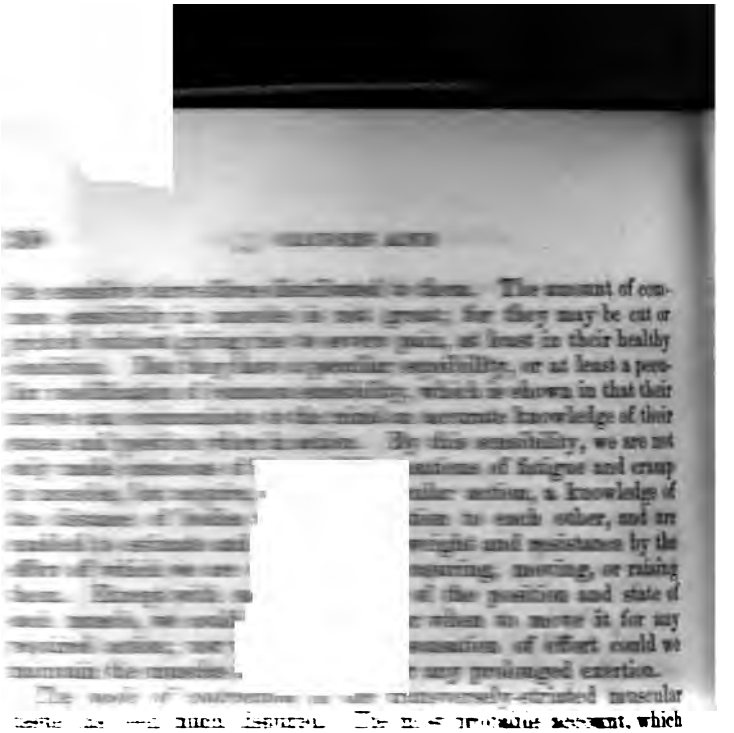
Fig. 80.



Muscular fibrils of the pig, magnified 720 diameters. *a*. An apparently single fibril, showing the quadrangular outline of the component particles, their dark central part and bright margin, and their lines of junction crossing the light intervals. *b*. A longitudinal segment of a fibre consisting of a number of fibrils still connected together. The dark cross stripes and light intervals on *b* are obviously occasioned by the dark specks and intervening light spaces respectively corresponding in the different fibrils. *c*. Other smaller collections of fibrils. From a preparation by Mr. Lealand. After Dr. Sharpey.

If the removal of nervous influence is long continued, as by division of the nerve supplying a muscle, or in cases of paralysis of long standing, the irritability, *i. e.*, the power of both perceiving and responding to a stimulus, may be lost; but this is chiefly because of the impaired nutrition of the muscular tissue, which ensues through its inaction (J. Reid). The irritability of muscles is also soon lost, unless a supply of arterial blood to them is kept up. Thus, after ligature of the main arterial trunk of a limb, the power of moving the muscles is partially or wholly lost, until the collateral circulation is established; and when, in animals, the abdominal aorta is tied, the hind legs are rendered almost powerless (Segalas, xxxii. p. 658). So, also, it is to the imperfect supply of arterial blood to the muscular tissue of the heart, that the cessation of the action of this organ in asphyxia is in some measure due (page 143).

Besides the property of contractility, the muscles, especially those of animal life and striated, possess sensibility by means of



...ion. The amount of con-... is not great; for they may be cut or ... without giving rise to severe pain, at least in their healthy ... They have a peculiar sensibility, or at least a pecu-... which is shown in that their ... accurate knowledge of their ... By this sensibility, we are not ... nations of fatigue and cramp ... ular action, a knowledge of ... ion to each other, and an ... ight and resistance by the ... moving, moving, or raising ... of the position and state of ... when we move it for any ... mination of effort could we ... any prolonged exertion.

The mode of contraction in the transversely-striated muscular ... is well known. The most popular account, which ... seen repeated lately in Dr Bowman's (1840–41), ... that the contraction is effected by an approximation of the ... parts of the fibrils, which, at the instant of contraction, ... their zigzag direction become closer, ... a condition which is rendered evident by the ... of the transverse lines seen on the surface of the ... fibre, which become broader and blacker. The appear-... of the zigzag lines into which the supposed fibres are ... is thought to be due to the contraction of a fibre which has ... contracted, and is not yet stretched again by some ... fibre, or whose extremities are kept close together by the ... of other fibres. The contraction is therefore a simple, ... according to Dr. Weber, an uniform, simultaneous, and steady ... of each fibre and its contents. When each fibril or fibre ... in length it gains in thickness; the contraction is a change of ... not of size: it is therefore not attended with any diminution ... bulk from condensation of the tissue. This has been proved for ... muscles, by making a mass of muscles, or many together, ... in a vessel full of water, with which a fine, perpendicular, ... tube communicates. Any diminution of the bulk of the ... muscle would be attended by a fall of fluid in the tube; ... when the experiment is carefully performed, the level of the ... in the tube remains the same, whether the muscle be con-... or not (Barzellotti; Mayo, xxxii. p. 886; Valentin, iv., ... cci, cxxiv.).[1]

[1] Edward Weber, however, states that a very slight diminution does take place in the bulk of a contracting muscle; but it is so slight as to be practically inconsiderable.

In thus shortening, muscles appear to swell up, becoming rounder, more prominent, harder, and apparently tougher. But this hardness of muscle in the state of contraction is not due to increased firmness or condensation of the muscular tissue, but to the increased tension to which the fibres, as well as their tendons and other tissues, are subjected from the resistance ordinarily opposed to their contraction. When no resistance is offered, as when a muscle is cut off from its tendon, not only is no hardness perceived during contraction, but the muscular tissue is even softer, more extensile, and less elastic than in its ordinary uncontracted state. (Ed. Weber, xv. art. *Muskelbewegung*.)

Heat is *developed* in the contraction of muscles. Becquerel and Breschet found with the thermo-multiplier about 1° of heat produced by each forcible contraction of a man's biceps; and when the actions were long continued, the temperature of the muscle increased 2°. It is not known whether this development of heat is due to chemical changes ensuing in the muscle, or to the friction of its fibres vigorously acting: in either case we may refer to it a part of the heat developed in active exercise, especially by the lower animals. And Nasse suspects that to it is due the higher temperature of the blood in the left ventricle; for he says it is always warmer in the left ventricle than in the left auricle, and that the blood in the latter is but little warmer than that on the right side of the heart. But these experiments need confirmation.

Sound is *produced* when muscles contract forcibly. Dr. Wollaston showed that this sound might be easily heard by placing the tip of the little finger in the ear, and then making some muscles contract, as those of the ball of the thumb, whose sound may be conducted to the ear through the substance of the hand and finger. A low shaking or rumbling sound is heard, the height and loudness of the note being in direct proportion to the force and quickness of the muscular action, and the number of fibres that act together, or, as it were, in time. To this sound of muscular contraction may be assigned, as already stated (p. 81), the first sound of the heart.

In the smooth, or simple muscular fibres, scarcely any of the phenomena just described have been observed. The fibres are believed to contract with a simple shortening, but the exact mode, and the phenomena attending it, have not been examined.

The two kinds of fibres have characteristic differences in the mode in which they act on the application of the same stimulus; differences which may perhaps be ascribed as much to their respective modes of connection with the nervous system as to their structures (see p. 372). When irritation is applied directly to a muscle with striated fibres, or to the motor nerve supplying it, contraction of the part irritated, and of that only, ensues; and this contraction is instantaneous, and ceases on the instant of withdrawing the irri-

tation. But when any part with smooth-fibred muscles, *e. g.*, the intestines, or bladder, or a duct, is irritated, the subsequent contraction ensues more slowly, extends beyond the part irritated, and, with alternating relaxations, continues for some time after the withdrawal of the irritation. Ed. Weber (xv. art. *Muskelbewegung*) has particularly illustrated the difference in the modes of contraction of the two kinds of muscular fibres by the effects of the electro-magnetic stimulus. The rapidly succeeding shocks, given by this means to the nerves of the [illegible] all the transversely-striated muscles a fixed state of [illegible]tion, which lasts as long as the stimulus is continu[illegible] withdrawal instantly ceases: but in the muscles with [illegible]hey excite, if any movement, only one that ensues sl[illegible]tively slight, alternates with rest, and continues for [illegible] stimulus is withdrawn.

In their mode of res[illegible]e stimuli, all the voluntary muscles, or those with [illegible] are alike; but among those with simple fibres ther[illegible]erences—a fact which tends to confirm the opinion that their peculiarity depends as much or more on their connection with nerves and ganglia than on their own properties. According to Weber, the ureters and gall-bladder are the parts least excited by stimuli: they do not act at all till the stimulus has been long applied, and then contract feebly and in a small extent. The contractions of the cæcum and stomach are quicker and wider spread: still quicker those of the iris, and of the urinary bladder, if it be not too full. The actions of the small and large intestines, the vas deferens, and pregnant uterus are yet more vivid, more regular, and more sustained; and they require no more stimulus than that of the air to excite them. The heart is quickest and most vigorous of all the muscles of organic life in contracting upon irritation, and appears in this, as in nearly all other respects, like the connecting member of the two classes of muscles.

All the muscles retain their property of contracting under the influence of stimuli applied to them, or to their nerves, for some time after death, the period being longer in cold-blooded than in warm-blooded Vertebrata, and shorter in birds than in Mammalia. It would seem as if the more active the respiratory process in the living animal, the shorter is the time of duration of the irritability in the muscles after death; and this is confirmed by the comparison of different species in the same order of Vertebrata. But the period during which this irritability lasts is not the same in all persons, nor in all the muscles of the same persons. In man it ceases, according to Nysten, in the following order: first, in the left ventricle, then in the intestines and stomach, the urinary bladder, right ventricle, œsophagus, iris; then in the voluntary muscles of the trunk, lower and upper extremities; lastly, in the left and right auricle of the heart.

After the muscles of the dead body have lost their irritability r capability of being excited to contraction by the application of a timulus, they spontaneously pass into a state of contraction, appaently identical with that which ensues during life.[1] It affects all he muscles of the body; and, where external circumstances do not revent it, commonly fixes the limbs in that which is their natural posture of equilibrium or rest. Hence, and from the simultaneous contraction of all the muscles of the trunk, is produced a general tiffening of the body, constituting the *rigor mortis* or *post-mortem rigidity*.

The muscles are not affected exactly simultaneously by the *post-mortem* contraction, but rather in succession. It affects the neck nd lower jaw first; next, the upper extremities, extending from bove downwards; and lastly reaches the lower limbs; in some rare instances only, it affects the lower extremities before, or simultaneously with, the upper extremities. It usually ceases in the order n which it began; first, at the head, then in the upper extremities, nd lastly, in the lower extremities. According to Sommer, it ever commences earlier than ten minutes, and never later than even hours, after death; and its duration is greater in proportion o the lateness of its accession.

Since the rigidity does not ensue until muscles have lost the apacity of being excited by external stimuli, it follows that all ircumstances which cause a speedy exhaustion of muscular irritaility, induce an early occurrence of the rigidity, while conditions y which the disappearance of the irritability is delayed are succeeded by a tardy onset of this rigidity. Hence its speedy occurence and equally speedy departure in the bodies of persons exausted by chronic diseases; and its tardy onset and long continuance fter sudden death from acute diseases. In some cases of sudden eath from lightning, violent injuries, or paroxysms of passion, the igor mortis appears not to occur at all; but this is not always the ase. (See lxxi. May 16, 1851.) It may indeed, perhaps, be oubted whether there is really a complete absence of the *post-ortem* rigidity in any such cases; for the experiments of M. rown-Séquard with electro-magnetism make it probable that the igidity may supervene immediately after death, and then pass way with such rapidity as to be scarcely observable. Thus he ook five rabbits, and killed them by removing their hearts. In he first, rigidity came on in 10 hours and lasted 192 hours; in the econd, which was feebly electrified, it commenced in seven hours

[1] If, however, arterial blood be made to circulate through the body or rough a limb, the contraction of the muscles thus supplied with blood, ay, according to Brown-Séquard, be suspended, and the muscles again lmit of contracting on the application of a stimulus (exc. Oct. 1851, p. 12; and ccl.).

and lasted 144; in the third, which was more strongly electrified, it came on in two, and lasted 72 hours; in the fourth, which was still more strongly electrified, it came on in one hour, and lasted 20; while in the last rabbit, which was submitted to a powerful electro-galvanic current, the rigidity ensued in seven minutes after death, and passed away in 25 minutes. From this it appears that the more powerful the electric current, the sooner does the rigidity ensue, and the shorter and as the lightning-shock is so much more powe linary electric discharge, the rigidity may ensue so h and pass away so rapidly as to escape detection exercised on the onset and duration of *post-morte* ses which exhaust the irrita- bility of the muscles. d in further experiments by the same physiolog nd that the rigor mortis en- sued far more ra a shorter period in those muscles which had lectrified just before death, than in the rest when had not been thus acted upon (cxix. 1849).

The occurrence of rigor mortis is not prevented by the previous existence of paralysis in a part, provided the paralysis has not been attended with very imperfect nutrition of the muscular tissue.

The rigidity affects the involuntary as well as the voluntary muscles, whether they are constructed of striped or unstriped fibres. The rigidity of involuntary muscles with striped fibres is shown in the contraction of the heart after death (page 73), when it constitutes what has been called concentric hypertrophy. The contraction of the muscles with unstriped fibres is shown by an experiment of Valentin (iv. Bd. ii. p. 36), who found that if a graduated tube be connected with a portion of intestine taken from a recently slain animal, filled with water and tied at the opposite end, the water will in a few hours rise to a considerable height in the tube, owing to the contraction of the intestinal walls. It is yet better shown in the arteries, of which all that have muscular coats contract after death, and thus present the roundness and cord-like feel of the arteries of a limb lately removed, or a body recently dead. Subsequently they relax, as do all the other muscles, and feel lax and flabby, and lie as if flattened and with their walls nearly in contact.[1]

Actions of Muscles.—The simplest division of muscular actions, and one which, for practical use, is most convenient, is into the voluntary and involuntary actions. But it is comparatively useless and uninstructive in the consideration of the general physiology of muscular movements; for, as we have seen, the structure of mus-

[1] Several interesting points in relation to *post-mortem* rigidity, may be found in Mr. W. F. Barlow's Papers on Muscular Contractions after Death from Cholera (lxxi. 1849–50).

cles does not exactly correspond with their having habitually the voluntary or the involuntary mode of action; neither can any muscle be said, unconditionally, to be either voluntary or involuntary, since many involuntary movements are performed by muscles subject to the will, and many muscles that are commonly independent of the will are liable to be affected by it or other acts of the mind. More than all, whether a muscle is involuntary or not depends not on itself, but on the nervous system; for, if the brain be removed or inactive, all the muscles become involuntary ones.

Neglecting, therefore, this distinction, it will be more instructive to follow Müller in an enumeration of the modes in which movements may be excited, either in single muscles, or in groups of muscles combined for united or opposite actions.

1. The first class of movements may be named *automatic*, the parts seeming to "have in themselves the power of motion,"[1] and not only the power, but the mode and plan.

These may include all those muscular actions which are not dependent on the will or any other act of the mind; which are either persistent, or periodical with a regular rhythm; and are dependent on normal natural causes seated in the nerves or the central organs of the nervous system. The cause of the rhythmic movements may be, as has been shown, either in the sympathetic or the cerebro-spinal nervous centres, but never in nerve-fibres. Of the automatic movements dependent chiefly on the sympathetic, the principal are those of the heart, the intestinal canal, uterus, and urinary bladder. The automatic movements of the heart are nearly like those of the animal muscles, quick, and succeeding each other quickly; those of the other organs are more gradual and more enduring, and their intervals of rest are much longer. Whether this difference be owing to the different structure of the muscle, or to the nature of the nervous influence, has been already considered but not decided.

It is a characteristic of the automatic movements of all the viscera of organic life that a certain order of succession is observed in the contractions; one part of the viscus contracts before another, and the motion thus traverses the organ in a determinate direction during each period of the rhythm. In the heart, the motion commences in the venæ cavæ, and proceeds through the auricles and ventricles, and then, after an interval, is resumed in the venæ cavæ (p. 74). In the intestine, the movement travels in a vermicular manner from above downwards; and a second movement, beginning at the upper part of the intestine before the first has completed its course, affects the parts in the same order. The action of stimuli

[1] What Müller names "movements excited by heterogeneous stimuli," are here omitted, because of the doubt whether any such occur naturally.

antagonistic movements. There are groups of muscles opposed to each other in their action in almost all parts of the body. The extremities have flexors and extensors, supinators and pronators, abductors and adductors, and rotators inwards and rotators outwards. When the muscles of one lateral half of the face are paralyzed, those of the opposite half of it draw the features towards their side. The tongue, when one half of it is paralyzed, may be drawn to the opposite side. Hence it would appear that the muscular fibres, especially those of animal life, are constantly in a state of slight contraction; and that the state of inaction of the different parts of our body does not indicate an absolutely relaxed condition of the muscles, but rather that the different groups of muscles antagonize and balance each other; and that when the position of a part is changed from the medium state of apparent rest, one or more of the muscles, already in a state of antagonistic action, are merely thrown into more powerful contraction.

When muscles have few or no antagonists, they always tend to give to the parts on which they act a determinate position. Thus there are numerous muscles which rotate the thigh outwards, while the rotation inwards can be effected but feebly by the tensor vaginæ femoris. Hence arises the involuntary tendency to the turning outwards of the whole limb in walking, sitting, or lying. The sphincters are also muscles which have no proper antagonists. The constant occlusion of the orifices of the viscera by the sphincters can be accounted for, therefore, by the fact of the contraction of muscles not wholly ceasing in the state of apparent rest, and of their having no antagonizing muscles; without its being necessary to suppose that a constant current of nervous influence is transmitted specially to them.

3. *Reflex Movements.*—The character of the reflected movements has been already explained (p. 301, &c.). They include all muscular actions which arise from impressions on centripetal nerves exciting motor nerves to action through the intervention of the nervous centres; and arrange themselves into two principal groups, of which the first may include the reflex movements determined by the brain and spinal cord.

4. Of the *associate* or *consensual movements* the peculiarity consists in the voluntary impulse to one motion giving rise to the production of other motions contrary to, or independently of, the will; thus, whenever the eye is voluntarily directed inwards, the iris contracts. The less perfect the action of the nervous system, the more frequently do associate movements occur. It is only by education that we acquire the power of confining the influence of volition, in the production of voluntary motions, to a certain number of nervous fibres issuing from the brain. An awkward person

in performing one voluntary movement makes many others, which are produced involuntarily by consensual nervous action. In the piano-forte player we have an example, on the other hand, of the faculty of insulation of the nervous influence in its highest perfection. The motions most prone to be associated involuntarily are those of the corresponding parts of the two sides of the body: as the motions of the irides, of the muscles of the ear, of the eyelids, and of the extremities in the attempt to effect opposed motions. Some of the most remarkable facts illustrating the association and antagonism of muscular actions are presented by the muscles which move the eyes (p. 345).

The organic muscles al ome measure, subject to the laws of association. The frequency and force of the heart's action during mus ns of the body are probably in some measure owing t The action of the voluntary muscles has an influenc the intestinal canal, and on that of the urinary bl ne is aware how beneficial muscular exercise is in e regularity of the muscular action of the intestine rity of excretion.

5. Of the *moveme* *certain states of the mind* there are three classes: pendent on mere ideas passing through the mind; those arising from the passions, emotions, or affections; and voluntary movements.

Certain groups of muscles of the animal system are in a constant state of proneness to involuntary motion, owing to the susceptibility of their nerves, or rather of the parts of the brain from which they arise, to be excited by ideas. Thus all the respiratory muscles, including those supplied by the facial nerve, may be excited to action merely by particular states of the mind. Any sudden change in the state of the mind, a sudden change of thought, such as occurs when the idea of the ridiculous arises in the mind, without any passion being excited, is capable of giving rise to a corresponding action of the nerves, evidenced in the muscles of the face and the respiratory muscles. Yawning, inasmuch as it can be excited by the mere idea, or by seeing or hearing another yawn, belongs to the same class of movements. The disposition to the movements of the features and the respiratory muscles that constitute laughing and yawning, exists previously; and is manifested when the idea gives to the nervous force the determinate direction. Ideas of fearful or detestable objects suddenly excited, even when called up by mere fictions, occasion, in persons of excitable temperament, the motion of shuddering; and the same occurs sometimes from the mere thought of a disgusting medicine: vomiting, indeed, may be produced by the mere recollection of a disagreeable taste.

It is again principally the respiratory portion of the nervous system which is involuntarily excited to the production of muscular

actions by the passions and emotions of the mind. The change in the state of the brain seems to be propagated to the medulla oblongata, which causes a change of action in the respiratory muscles, through the medium of their nerves, including the facial nerve which is pre-eminently the nerve of expression.

The exciting passions give rise to spasms, and frequently even to convulsive motions affecting the muscles supplied by the respiratory and facial nerves. Not only are the features distorted, but the actions of the respiratory muscles are so changed as to produce the movements of crying, sighing, and sobbing. During the sway of depressing passions, such as fear, or terror, all the muscles of the body become relaxed—the motor influence of the brain and spinal cord being depressed. The feet will not support the body, the features hang as without life, the eye is fixed, the look is completely vacant, and void of expression, the voice feeble or extinct. Frequently, the state of the feelings under the influence of passion is of a mixed character; the mind is unable to free itself from the depressing idea; yet the effort to conquer this gives rise to an exciting action in the brain. In these mixed passions, the expression of relaxation in certain muscles—in the face, for example—may be combined with the active state of others; so that the features are distorted, whether in consequence merely of the antagonising action of the opposite muscles being paralyzed, or by a really convulsive contraction. Disorderly as the mode in which these emotional influences are exercised may seem to be, yet to each emotion certain combined movements are appropriated, and become *expressive* of it. The nerves of certain groups of muscles seem to be naturally combined to act together when the appropriate emotion is felt, as the respiratory nerves are for the common respiratory movements. Like these movements, also, the emotional movements may be controlled by the will, though essentially independent of it, and though, when the stimulus exciting them is very strong, they may occur in opposition to the effort of the will. With these actions of the muscles of animal life, those of organic life are often associated; the disturbed action of the heart during mental emotions is an instance of such association.

Of the *voluntary movements* we have already spoken in connection with the physiology of the motor nerves and the brain. In all the former instances, we are scarcely, or not at all, conscious of the movements that take place, or are only conscious of them by other senses than the muscular sense, as by seeing the movement. And this may be connected with the probability that the central organs determining these movements are not the organs in which the mind can either clearly discern sensations or deliberately exercise the will (see p. 335). In the voluntary motions we have both consciousness and intention; though not in all cases an equal

degree of either, for in movements habitually performed we are hardly either conscious or intent.

We have no knowledge how the will acts in the brain, through which alone its full influence can be directed to the nerves (see p. 336); but the influence of the will on the motor fibres, is not a solitary fact of its kind. Through the brain we have the power of voluntarily directing the mind to all the cerebral and spinal nerves, even to the nerves of common sensation, and the nerves of special sense; we exercise this power whenever we *attend* to sensations. If two persons are addressing different words to our opposite ears, we can by attention follow what is said by the one, while we leave what the [illegible] noticed. The same circumstance is observed in the [illegible]ltaneous impressions on different senses. Accordi[illegible]ction we give our attention, we cease to see distinctl[illegible]rt the power of hearing to a greater degree, and *vice* [illegible]ly one object at a time can be taken cognizance of [illegible]y of attention (see p. 293). Thus, we have the powe[illegible] the attention according to our will; the will has l[illegible]nfluence as in the production of voluntary motions. [illegible]rence is, that in the latter case the motor nerve-fil[illegible] in a state of repose, are excited to action; while in [illegible] to the impressions on the sensitive nerves, the action of the will consists in rendering the sensation more intense or distinct. Neither is the power of the will limited to the motor and sensitive nerves; it also influences the mental operations; we have the power of voluntarily directing our thoughts. In short, we see that the voluntary effort of the mind can be directed upon motor or sensitive nerves, or made to affect the mental operations; an act of volition is nothing else than the voluntary and conscious direction of the nervous forces in the brain upon different cerebral apparatus; and on the part of the brain subjected to this voluntary action of the nervous principle it depends, whether the effect shall be a muscular movement, a more distinct perception, or an idea connected with some sensible object.

As a general rule, a voluntary movement is more difficult the smaller the number of nervous fibres required to be excited, and the smaller the part to be moved. The nervous force more readily excites many than few nervous fibres to action; hence the tendency to the associate movements described at page 387. It is doubtful whether distinct portions of a long muscle can be voluntarily excited to independent and separate action. The action of the nervous force is therefore less capable of localization when excited by volition than when determined by accidental involuntary stimuli. From external causes very small parts of a muscle, for example, of the biceps of the arm, are seen to contract separately; but this never occurs from voluntary influence. The power of confining the vol-

untary excitement of the nervous principle to distinct groups of fibres is increased by much exercise, and the more frequently certain groups of fibres are excited to action by the influence of the will, the more capable do they become of isolated action; this is exemplified in performers on the piano-forte, &c.

Motions very frequently performed occur at last whenever the nervous influence in the brain receives, in the slightest degree, the direction necessary to produce them; as if the conducting power of the nervous fibres, and the combining power of the nervous centres, increased with the frequency of their excitement. Hence the facility of the habitual movements; hence the mimic movements of the hands in speaking; and thus obscure ideas, without any distinct consciousness, often give rise to determinate and appropriate motions, provided these motions have been previously many times excited in the same manner; the effort of the will in producing these movements being as obscurely felt as the sensation or idea that led to them.

CHAPTER XVII.

OF VOICE AND SPEECH.

In nearly all air-breathing vertebrate animals there are arrangements for the production of sound, or *voice*, in some part of the respiratory apparatus. In many animals, the sound admits of being variously modified and altered during and after its production; and, in man, one of the results of such modification is *speech*.

Mode of Production of the Human Voice.

It has been proved, by observations on living subjects, as well as by experiments on the larynx taken from the dead body, that the sound of the human voice is the result of the inferior laryngeal ligaments, or vocal cords, which bound the glottis, being thrown into vibrations by currents of expired air impelled over their edges. Thus, if a free opening exists in the trachea, the sound of the voice ceases, but returns on the opening being closed. An opening into the air-passages above the glottis, on the contrary, does not prevent the voice being formed. M. Magendie, also, has shown that the voice is not lost, though the epiglottis, the superior ligaments of the larynx, and the upper part of arytenoid cartilages be injured. The same may be observed in cases of disease; and in injuries, when the vocal cords are exposed, they may be seen vibrating during the emission of sound. Injury of the laryngeal

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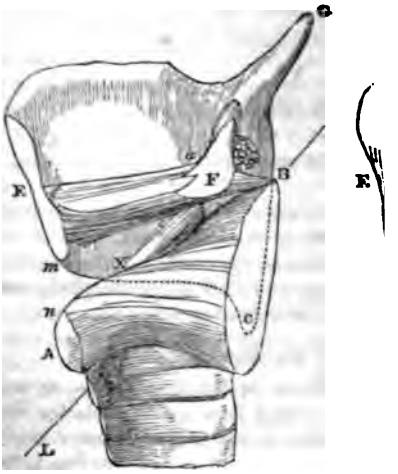
the fissure of the glottis may be r

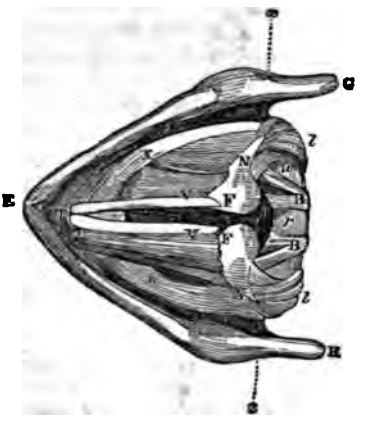
The vocal ligaments, therefore,
organs of the mere voice: the mod
by other parts as well as by them
enable them to vibrate like tense
large quantity of elastic tissue; a

Fig. 8.



crico-thyroid muscles (Fig. 81, A K); or by the retraction of the arytenoid cartilages (Fig. 82, I I, N F), which are moved backwards by the posterior crico-arytenoid muscles (Fig. 82 N X), at the same time that they are approximated by the posterior arytenoid (Fig. 81, *s*). The length of the fissure of the glottis (Fig. 82, between V V) depends on the degree to which the cords are thus stretched; and their degree of tension probably depends not only on the degree in which their stretching is resisted by their proper tissue, but also, in some measure, on the action of the thyro-arytenoid muscles (Fig. 82, V *k f*), which are closely connected to them along their whole length.

Fig. 82.



Bird's-eye view of larynx from above. G E H, the thyroid cartilage, embracing the ring of the cricoid *r u x w*, and turning upon the axis *x z*, which passes through the lower horn C, Fig. 81—N F, N F, the arytenoid cartilages, connected by the arytenoideus transversus—T V, T V, the vocal ligaments—N X, the right crico-arytenoideus lateralis (the left being removed)—V *k f*, the left thyro-arytenoideus (the right being removed)—N *l*, N *l*, the crico-arytenoidei postici—B B, the crico-arytenoid ligaments.

The aperture of the glottis is narrowed by the approximation of the arytenoid cartilages, which is effected by the arytenoid muscles: it is dilated by the lateral crico-arytenoid (N X), which draw the arytenoid cartilages asunder.

The experiments of the Rev. Mr. Willis (cxliii. 1832), on instruments made in imitation of the larynx, have shown that, besides being made tense, the vocal cords, in order to produce a proper vocal sound, must have their inner edges parallel. In the ordinary position of the glottis, during respiration without vocalization, he supposes that the lips of the glottis are inclined from each other (as at *a a*, Fig. 84, which is an imaginary transverse perpendicular section of the vocal tube), and that to produce voice they must assume the parallel state (as at *a a*, Fig. 83); and he attributes to the thyro-arytenoid muscles the office of placing the ligaments in this position.

In vocalizing, the ligaments vibrate in their entire breadth, and with them the thyro-arytenoid muscles, and (to an extent corresponding to the force with which they vibrate) the adjacent elastic tissues of the larynx and other parts, and the air in and beyond

the respiratory passages. For the deepest notes, the vocal ligaments are much relaxed by the approximation of the thyroid to the arytenoid cartilages. The lips or margins of the glottis are,

Fig. 83. Fig. 84.

Figs. 83, 84. a a. , cords. (From Prof. Willis.)

in this state of the larynx, not only devoid of tension—they are, when at rest, even wrinkled—but they become stretched by the current of air, and thus acquire the degree of tension necessary for vibration. From the deepest note thus produced, the vocal sounds may be raised about an octave by allowing the vocal cords to have the slight degree of tension which the elastic crico-thyroid ligament can give them, by drawing the thyroid cartilage towards the cricoid. The medium state, in which the cords are neither relaxed and wrinkled nor stretched, is the condition for the middle notes of the natural voice, and those which are most easily produced in singing. (The ordinary tones of the voice in speaking are intermediate between these and the deep bass notes.) The higher notes of the natural voice are produced by the lateral compression of the vocal cords, and the narrowing of the space between them by means of the thyro-arytenoid muscles; and further, by increasing the force of the current of air.[1]

In the quiescent state, the aperture of the glottis is widely open and somewhat triangular, the base of the triangle corresponding to the space between the separated arytenoid cartilages. In inspiration the glottis is slightly dilated, in expiration contracted; and at the moment of the emission of sound it is more narrowed, the margins of the arytenoid cartilages being brought into contact, and the edges of the vocal cords approximated and made parallel. The degree of approximation usually corresponds to the height of the note pro-

[1] For the laws regulating the vibration of membranous tongues, and other sounding bodies, and for further details of the mode of production of the voice, and of the circumstances by which it is modulated, consult Müller.

duced; but probably not always, for the width of the aperture has no essential influence on the height of the note, as long as the vocal cords have the same tension; only, with a wide aperture, the tone is more difficult to produce, and is less perfect, the rushing of the air through the aperture being heard at the same time.

No true vocal sound is produced at the posterior part of the aperture of the glottis, that, viz., which is formed by the space between the arytenoid cartilages. For, as Müller's experiments showed, if the arytenoid cartilages be approximated in such a manner that their anterior processes touch each other, but yet leave an opening behind them as well as in front, no second vocal tone is produced by the passage of the air through the posterior opening, but merely a rustling or bubbling sound; and the height or pitch of the note produced is the same whether the posterior part of the glottis be open or not, provided the vocal cords maintain the same degree of tension.

Vocal sounds can be produced not only when the lips of the glottis are separated by a narrow interval, but even when to the eye they appear to be in contact, especially if the vocal cords are much relaxed; in which case the vibrations of the lips of the glottis are very strong. The notes emitted in such a condition of the glottis are stronger and fuller; but, provided the length of the cords be the same, and the tension in both cases equally slight, the height of the note is not influenced by the cords being in contact, or by their being separated by a narrow interval.

The *epiglottis*, by being pressed down so as to cover the superior cavity of the larynx, serves to render the notes deeper in tone, and at the same time somewhat duller, just as covering the end of a short tube placed in front of caoutchouc tongues lowers the tone. In uttering very deep notes during life, we evidently employ the epiglottis in this way; at least, such seems to be the object of the retraction and depression of the tongue while we press down the head in front, in endeavoring to produce very deep notes. In no other respect does the epiglottis appear to have any effect in modifying the vocal sounds.[1]

Applications of the Voice in Singing and Speaking.

The notes of the voice thus produced may observe three different kinds of sequence. The first is the monotonous, in which the notes have all nearly the same pitch, as in ordinary speaking; the variety of the sounds of speech being owing to articulation in the mouth.

[1] The influence which the two portions of the vocal tube, viz., that furnished by the trachea and that by the air-passages in front of the larynx, exercise in modulating the voice is not yet satisfactorily determined. For observations on the subject consult Müller (*l. c.*); Mr. Bishop (clxxxi. 1836); and Mr. Willis (cxliii. 1832).

In speaking, however, occasional syllables generally receive a higher intonation for the sake of accent. In poetry, there is rhythm in addition to the accent, but the modulation of music is wanting. The second mode of sequence is the successive transition from high to low notes, and *vice versâ*, without intervals; such as is heard in the sounds, which, as expressions of passion, accompany crying in men, and in the howling and whining of dogs. The third mode of sequence of the v[illegible] musical, in which each sound has a determinate n[illegible]ns, and the number of vibrations in the success[illegible]e same relative proportions as characterize the [illegible]l scale.

The *compass of* [illegible]ent individuals comprehends one, two, or three [illegible]—that is, in persons apt for singing—it extends [illegible] octaves. But the male and female voices comm[illegible]fferent points of the musical scale. The lowest [illegible] voice is about an octave higher than the lowest of t[illegible], the highest note of the female voice about an octave higher than the highest of the male. The compass of the male and female voices taken together, or the entire scale of the human voice, includes about four octaves. The principal difference between the male and the female voice is, therefore, in their pitch; but they are also distinguished by their tone—the male voice is not so soft.

The voice presents other varieties besides the male and female; there are two kinds of male voice, technically called the bass and tenor, and two kinds of female voice, the contralto and soprano, all differing from each other in tone. The bass voice usually reaches lower than the tenor, and its strength lies in the low notes; while the tenor voice extends higher than the bass. The contralto voice has generally lower notes than the soprano, and is strongest in the lower notes of the female voice; while the soprano voice reaches higher in the scale. But the difference of compass, and of power in different parts of the scale, are not the essential distinctions between the different voices; for bass singers can sometimes go very high, and the contralto frequently sings the high notes like soprano singers. The essential difference between the bass and tenor voices, and between the contralto and soprano, consists in their tone or "timbre," which distinguishes them even when they are singing the same note. The qualities of the barytone and mezzo-soprano voices are less marked; the barytone being intermediate between the bass and tenor, the mezzo-soprano between the contralto and soprano. They have also a middle position as to pitch in the scale of the male and female voices.

The different pitch of the male and the female voice depends on the different length of the vocal cords in the two sexes; their relative length in men and women being as three to two. The differ-

ence of the two voices in tone or "timbre" is owing to the different nature and form of the resounding walls, which in the male larynx are much more extensive, and form a more acute angle anteriorly. The different qualities of the tenor and bass, and of the alto and soprano voices, probably depend on some peculiarities of the ligaments and the membranous and cartilaginous parietes of the laryngeal cavity, which are not at present understood, but of which we may form some idea, by recollecting that musical instruments made of different materials, *e. g.*, metallic and gut strings, may be tuned to the same note, but that each will give it with a peculiar tone or "timbre."

The larynx of boys resembles the female larynx; their vocal cords before puberty have not two-thirds the length which they acquire at that period; and the angle of their thyroid cartilage is as little prominent as in the female larynx. Boys' voices are alto and soprano, resembling in pitch those of women, but differing somewhat from them in tone, and louder. But, after the larynx has undergone the change produced during the period of development at puberty, the boy's voice becomes bass or tenor. While the change of form is taking place, the voice is said to crack; it becomes imperfect, frequently hoarse and crowing, and is unfitted for singing until the new tones are brought under command by practice. In eunuchs, who have been deprived of the testes before puberty, the voice does not undergo this change. The voice of most old people is deficient in tone, unsteady, and more restricted in extent: the first defect is owing to the ossification of the cartilages of the larynx and the altered condition of the vocal cords; the want of steadiness arises from the loss of nervous power and command over the muscles; the result of which is here, as in other parts, a tremulous motion. These two causes combined render the voice of old people void of tone, unsteady, bleating, and weak.

In any class of persons arranged, as in an orchestra, according to the characters of voices, each would possess, with the general characteristics of a bass, or tenor, or any other kind of voice, some peculiar character by which his voice would be recognized from all the rest. The conditions that determine these distinctions are, however, quite unknown. They are probably inherent in the tissues of the larynx, and as indiscernible as the minute differences that characterize men's features; in likeness to which one often observes hereditary and family peculiarities of voice as well marked as those of the limbs or face.

Most persons, particularly men, have the power, if at all capable of singing, of modulating their voices through a double series of notes of different character: namely, the notes of the natural voice, or *chest-notes*, and the *falsetto notes*. The natural voice, which alone has been hitherto considered, is fuller, and excites a distinct sensa-

tion of much stronger vibration and resonance than the falsetto voice, which has more of a flute-like character. The deeper notes of the male voice can be produced only with the natural voice, the highest with the falsetto only; the notes of middle pitch can be produced either with the natural or falsetto voice; the two registers of the voice are therefore not limited in such manner that one ends when the other begins, but they run in part side by side.

The natural, or chest-notes, are produced by the ordinary vibrations of the vocal cords. The mode of production of the falsetto notes is still obscure. [illegible] are thought to be due to vibrations of only the [illegible] of the vocal cords. In the opinion of Petrequin a[illegible]), they do not result from vibrations of the vocal [illegible]t from vibration of the air passing through the [illegible] glottis, which they believe assumes at such times [illegible] the *embouchure* of a flute. Others (considering so[illegible] ilarity which exists between the falsetto notes and [illegible], called harmonic, which are produced when, by t[illegible] a harp-string at a particular point, only a portion [illegible] lowed to vibrate) have supposed that, in the falsetto notes, portions of the vocal ligaments are thus isolated and made to vibrate while the rest are held still. The question cannot yet be settled: but any one in the habit of singing may assure himself, both by the difficulty of passing smoothly from one set of notes to the other, and by the necessity of exercising himself in both registers, lest he should become very deficient in one, that there must be some great difference in the modes in which their respective notes are produced.

The strength of the voice depends partly on the degree of capability of vibration of the vocal cords; and partly on the fitness for resonance of the membranes and cartilages of the larynx, of the parietes of the thorax, lungs, and cavities of the mouth, nostrils, and communicating sinuses. It is diminished by anything which interferes with such capability of vibration. The intensity or loudness of a given note cannot be rendered greater by merely increasing the force of the current of air through the glottis; for increase of the force of the current of air, *cæteris paribus*, raises the pitch both of the natural and the falsetto notes. Yet, since a singer possesses the power of increasing the loudness of a note from the faintest "piano" to "fortissimo," without its pitch being altered, there must be some means of compensating the tendency of the vocal cords to emit a higher note when the force of the current of air is increased. This means evidently consists in modifying the tension of the vocal cords. When a note is rendered louder and more intense, the vocal cords must be relaxed by remission of the muscular action, in proportion as the force of the current of the

breath through the glottis is increased. When a note is rendered fainter, the reverse of this must occur.

The length of the larynx and trachea below the vocal ligaments has, according to Müller, no perceptible influence in the tone or pitch of the voice;—he thinks that the elongation of the vocal tube in front of the glottis by the descent of the larynx, only facilitates the formation of the deep notes, and the shortening of the tube by the ascent of the larynx that of the high notes. Mr. Bishop states, however, that the trachea is not really lengthened by the ascent of the larynx; he finds that it is raised out of the thorax nearly to the same extent as the larynx is elevated; he therefore concludes, that an absolute shortening of the entire vocal tube, including the trachea and the cavities above the glottis, is produced by the elevation of the larynx towards the base of the skull. But the variation in the length of the tube being insufficient to render it capable of adjusting itself to the whole range of vocal tones, both he and Mr. Wheatstone (clxxxii. p. 373) suppose that the defect is supplied by the varying tension of the walls of the trachea, and by the diminished diameter of the trachea during the ascent of the larynx. A still further influence on the voice is attributed to the trachea by Mr. Wheatstone. He has observed, that a column of air may not only vibrate, by reciprocation with another body whose vibrations are isochronous with its own, but also when the number of its own vibrations are any multiple of those of the sounding body. Such would be the vibrations of the column of air in the trachea divided into harmonic lengths, with relation to the vibrations of the vocal cords. The falsetto notes, he suggests, may be the result of the vibrations of the harmonic subdivisions of the column of air in the trachea.

The *arches of the palate and the uvula* become contracted during the formation of the higher notes: but their contraction is the same for a note of given height, whether it be falsetto or not: and in either case the arches of the palate may be touched with the finger, without the note being altered. Their action, therefore, in the production of the higher notes, seems to be merely the result of involuntary associate nervous action, excited by the voluntarily increased exertion of the muscles of the larynx. If the palatine arches contribute at all to the production of the higher notes of the natural voice and the falsetto, it can only be by their increased tension strengthening the resonance.

The office of the *ventricles of the larynx* is evidently to afford a free space for the vibrations of the lips of the glottis: they may be compared with the cavity at the commencement of the mouth-piece of trumpets, which allows the free vibration of the lips.[1]

[1] Many of the conclusions respecting the physiology of the human voice which are stated in the foregoing pages are derived from, or illustrated by,

SPEECH.

Besides the musical tones formed in the larynx, a great number of other sounds can be produced in the vocal tube, between the glottis and the external apertures of the air-passages, the combination of which sounds into different groups to designate objects, properties, actions, &c., constitutes *language*. The languages do not employ all the sounds which can be produced in this manner, the combination of some with others being often difficult. Those sounds which are easy of combination enter, for the most part, into the formation of the greater number of languages. Each language contains a certain number of such sounds, but in no one are all brought together. Di[ffe]rent languages are characterized by the prevalenc[e] [o]f certain classes of these sounds while others are less fr[e]quent or [e]ther absent.

The sounds produced [by] the *articulate sounds*, are commonly divided into vow[e]ls and *consonants;* the distinction between which is, that the [fo]rmer are generated in the larynx, while those [are] produced by interruption of the current of air in [the] air-passages above the larynx. The term consonant [is] applied to these, because several of them are not properly [pro]nounced *consonantly with* a vowel. Thus, if it be attempted to pronounce aloud the consonants *b*, *h*, and *g*, or their modifications, *p*, *t*, *k*, the intonation only follows them in their combination with a vowel.

To recognize the essential properties of the articulate sounds, we must, according to Müller, first examine them as they are produced in whispering, and then investigate which of them can also be uttered in a modified character, conjoined with vocal tone. By this procedure, we find two series of sounds: in one, the sounds are mute, and cannot be uttered with a vocal tone; the sounds of the other series can be formed independently of voice, but are also capable of being uttered in conjunction with it.

All the vowels can be expressed in a whisper without vocal tone, that is, mutely. These mute vowel-sounds differ, however, in some measure, as to their mode of production, from the consonants. All the mute consonants are formed in the vocal tube above the glottis, or in the cavity of the mouth or nose, by the mere rushing of the air between surfaces differently modified in disposition. But the sound of the vowels, even when mute, has its source in the glottis, though the vocal cords are not thrown into the vibrations necessary for the production of voice; and the sound seems to be produced,

experiments with apparatus made in imitation of the larynx: for the complete account of these, and for suggestions how they may be yet further applied to the study of this part of physiology, consult the elaborate chapters by Muller; and the papers of Willis (cxliii. 1832) Wheatstone (clxxxii.); Bishop (clxxxi. 1836); and the earlier writers to whom Müller refers.

by the passage of the current of air between the relaxed vocal cords. The same vowel-sound can be produced in the larynx when the mouth is closed, the nostrils being open, and the utterance of all vocal tone avoided. This sound, when the mouth is open, is so modified by varied forms of the oral cavity, as to assume the characters of the vowels, *a*, *e*, *i*, *o*, *u*, in all their modifications.

The cavity of the mouth assumes the same form for the articulation of each of the mute vowels as for the corresponding vowel when vocalized; the only difference in the two cases lies in the kind of sound emitted by the larynx. Kratzenstein and Kempelen have pointed out that the conditions necessary for changing one and the same sound into the different vowels, are differences in the size of two parts—the oral canal and the oral opening; and the same is the case with regard to the mute vowels. By oral canal, Kempelen means here, the space between the tongue and palate: for the pronunciation of certain vowels, both the opening of the mouth, and the space just mentioned, are wide; for the pronunciation of other vowels, both are contracted; and for others, one is wide the other contracted. Admitting five degrees of size, both of the opening of the mouth, and of the space between the tongue and palate, Kempelen thus states the dimensions of these parts for the following vowel sounds :—

Vowel.	Sound.	Size of oral opening.	Size of oral canal.
a	as in far	5	3
a	" name	4	2
e	" theme	3	1
o	" go	2	4
oo	" cool	1	5

Another important distinction in articulate sounds is that the utterance of some is only of momentary duration, taking place during a sudden change in the conformation of the mouth, and being incapable of prolongation by a continued expiration. To this class belong *b*, *p*, *d*, and the hard *g*. In the utterance of other consonants the sounds may be *continuous;* they may be prolonged, *ad libitum*, as long as a particular disposition of the mouth and a constant expiration are maintained. Among these consonants are *v*, *m*, *n*, *f*, *s*, *r*, *l*. Corresponding differences in respect to the time that may be occupied in their utterance exist in the vowel-sounds, and principally constitute the differences of long and short syllables. Thus, the *a* as in "far" and "fate," the *o* as in "go" and "fort," may be indefinitely prolonged; but the same vowels (or more properly different vowels expressed by the same letters), as in "can" and "fact," in "dog" and "rotten," cannot be prolonged.[1]

[1] The minuter physiology of speech may be best studied in Müller (xxxii.); or in the remarkable work by Ammann, from which even Müller has been instructed, entitled "Dissertatio de Loquela, 1700.

All sounds of the first or explosive kind are insusceptible of combination with vocal tone ("intonation"), and are absolutely mute; nearly all the consonants of the second or continuous kind may be attended with "intonation."

The peculiarity of speaking, to which the term *ventriloquism* is applied, appears to consist merely in the varied modification of the sounds produced in the larynx, in imitation of the modifications which voice ordinarily [illegible] nce, &c. From the observations of Müller and [illegible] i. 1840), it seems that the essential mechanism [illegible] ss of ventriloquism consist in taking a full ins[illegible] g the muscles of the chest and neck fixed, and [illegible] outh almost closed, and the lips and lower jaw [illegible] ible, while air is very slowly expired through [illegible] care being taken, also, that none of the expir[illegible] the nose. But, as observed by Müller, much [illegible] skill in imitating the voices coming from particular [illegible] sts in deceiving other senses than hearing. We never distinguish very readily the direction in which sounds reach our ear; and, when our attention is directed to a particular point, our imagination is very apt to refer to that point whatever sounds we may hear.

CHAPTER XVIII.

THE SENSES.

SENSATION consists in the mind receiving through the medium of the nervous system, and, usually, as the result of the action of an external cause, a knowledge of certain qualities or conditions, not of external bodies, but of the nerves of sense themselves; and these qualities of the nerves of sense are in all different, the nerve of each sense having its own peculiar quality.

There are two principal kinds of sensation, named common and special. The first is the consequence of the ordinary sensibility or feeling possessed by most parts of the body, and is manifested when a part is touched, or in any ordinary manner is stimulated. According to the stimulus, the mind perceives a sensation of heat, or cold, of pain, of the contact of hard, soft, smooth, or rough objects, &c. From this, also, in morbid states, the mind perceives itching, tingling, burning, aching, and the like sensations. In its greatest perfection common sensibility constitutes *touch* or *tact*. Touch is indeed usually classed with the special senses, and will be considered in the same group with them; yet it differs from them in being a

property common to many nerves, *e. g.*, all the sensitive spinal nerves, the pneumogastric, glosso-pharyngeal, and fifth cerebral nerves, and in its impressions being communicable through many organs.

Including the sense of touch, the special senses are five in number; the senses of smell, sight, hearing, taste, and touch. The manifestation of each of the first three depends on the existence of a special nerve; the optic for the sense of sight, the auditory for that of hearing, and the olfactory for that of smell. The sense of taste appears to be a property common to branches of the fifth and of the glosso-pharyngeal nerves.

The senses, by virtue of the peculiar properties of their several nerves, make us acquainted with the states of our own body; and thus, indirectly, inform us of such qualities and changes of external matter as can give rise to changes in the condition of the nerves. That which through the medium of our senses is actually perceived by the mind is, indeed, merely a property or change of condition of our nerves; but the mind is accustomed to interpret these modifications in the state of the nerves produced by external influences as properties of the external bodies themselves. This mode of regarding sensations is so habitual in the case of the senses which are more rarely affected by internal causes, that it is only on reflection that we perceive it to be erroneous. In the case of the sense of feeling or touch, on the contrary, where the peculiar sensations of the nerves perceived by the sensorium are excited as frequently by internal as by external causes, we more readily apprehend the truth. For it is easily conceived that the feeling of pain or pleasure, for example, is due to a condition of the nerves, and is not a property of the things which excite it. What is true of these is true of all other sensations; the mind perceives conditions of the optic, olfactory, and other nerves specifically different from that of their state of rest; these conditions may be excited by the contact of external objects, but they may also be the consequence of internal changes: in the former case the mind, having knowledge of the object through either instinct or instruction, recognizes it by the appropriate changes which it produces in the state of the nerves.

1. The special susceptibility of the different nerves of sense for certain influences—as of the optic nerve for light, of the auditory nerve for vibrations, and so on—is not due entirely to these nerves having each a specific irritability for such influences exclusively. For although in the ordinary events of life the optic nerve is excited only by the undulations or emanations of which light may consist, the auditory only by vibrations of the air, and the olfactory only by odorous particles, yet each of these nerves may have its peculiar properties called forth by other conditions. In fact, in whatever way and to whatever degree a nerve of special sense is stimulated,

dog were pricked, no signs of pain
his experiments seemed to show tha
are insusceptible of pain (lxii. t. iv

2. External impressions on a ne
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being produced by internal causes in
with sensitive nerves. The sensatio
therefore states or qualities proper
rendered manifest by exciting causes,
The sensation of smell, also, may be
the application of any odorous substan
influence of some internal condition
sensations of the sense of vision, namel
are also often perceived independently
So, also, whenever the auditory nerve
the sensations peculiar to it, as the s
&c., are perceived.

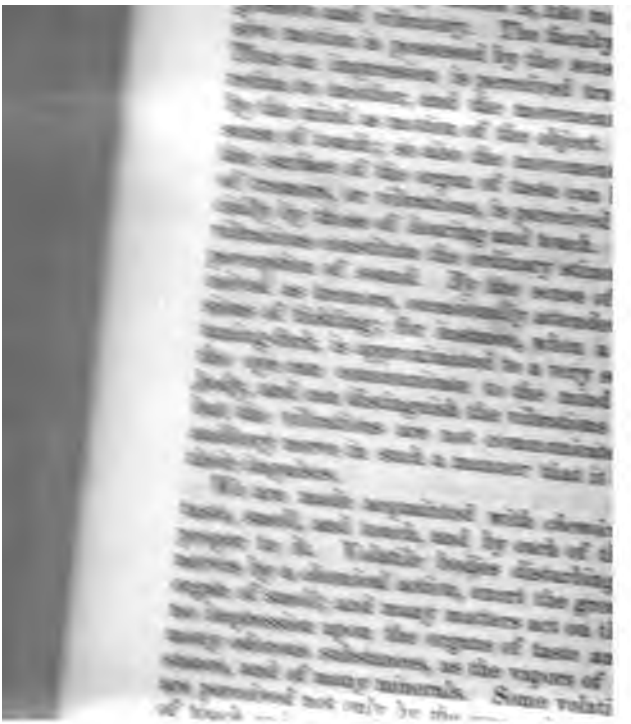
3. The same cause, whether interna
different senses different sensations; i
peculiar to it. For instance, one un
may act on all the nerves

sweeping over the surface. So also among *external* causes, the stimulus of electricity, or the mechanical influence of a blow, concussion, or pressure, excites in the eye the sensation of light and colors; in the ear, a sense of a loud sound or of ringing; in the tongue, a saline or acid taste; and at the other parts of the body, a perception of peculiar jarring or of the mechanical impression, or a shock like it.

4. Although in the cases just referred to, and in all ordinary conditions, sensations are derived from peculiar conditions of the nerves of sense, whether excited by external or by internal causes, yet the mind may have the same sensations independently of changes in the conditions of at least the peripheral portions of the several nerves, and even independently of any connection with the external organs of the senses. The causes of such sensations are seated in the parts of the brain in which the several nerves of sense terminate. Thus pressure on the brain has been observed to cause the sensation of light; luminous spectra may be excited by internal causes after complete amaurosis of the retina: and Humboldt states that, in a man who had lost one eye, he produced, by means of galvanism, luminous appearances on the blind side. Many of the various morbid sensations attending diseases of the brain, the vision of spectra, and the like, are of the same kind.

5. Again, although the immediate objects of the perception of our senses are merely particular states induced in the nerves, and felt as sensations, yet, inasmuch as the nerves of the senses are material bodies, and therefore participate in the properties of matter generally, occupying space, being susceptible of vibratory motion, and capable of being variously changed chemically as well as by the action of heat and electricity, they make known to the mind, by virtue of the different changes thus produced in them by external causes, not merely their own condition, but also some of the different properties and changes of condition of external bodies; as, *e.g.*, "extension," progressive and tremulous motion, chemical change, &c. The information concerning external nature thus obtained by the senses, varies in each sense, having a relation to the peculiar qualities or energies of the nerve.

All the senses are not equally adapted to impart the idea of *extension*. The nerve of vision and the nerves of touch, being capable of an exact perception of this property in themselves, make us acquainted with it in external bodies: and it is by these senses that we best, by seeing and feeling bodies, learn their extension and their relation to other objects and to ourselves. In the nerves of taste, the sensation of extension is less distinct, but not altogether deficient; for we are capable of distinguishing whether the seat of a bitter or sweet taste be the tongue, the palate, or the



xterior; but this is owing, not to anything in the nature of the erves themselves, but to the accompanying idea derived from ex-erience. For in the perception of sensations there is a combined ction both of the mind and of the nerves of sense; and the mind, y education or experience, has learned to refer the impressions it ceives to objects external to the body. Even when it derives mpressions from internal causes, it commonly refers them to ex-ernal objects. The light perceived in congestion of the retina eems external to the body: the ringing of the ears in diseases is felt as if the sound came from some distance: the mind referring it to the outer world from which it is in the habit of receiving the like impression (see p. 294).

8. Moreover, the mind not only perceives the sensations and interprets them according to ideas previously obtained, but it has a direct influence upon them, imparting to them intensity by its faculty of attention. Without simultaneous attention, all sensations are only obscurely, if at all, perceived. If the mind be torpid in indolence, or if the attention be withdrawn from the nerves of sense in intellectual contemplation, deep speculations, or an intense passion, the sensations of the nerves make no impression upon the mind; they are not perceived—that is to say, they are not communicated to the conscious "self," or with so little intensity, that the mind is unable to retain the impression, or only recollects it some time after, when it is freed from the preponderating influence of the idea which had occupied it.

This power of attention to the sensations derived from a single organ, may also be exercised in a single portion of a sentient organ, and thus enable one to discern the detail of what would, otherwise, be a single sensation. For example, by well-directed attention one can distinguish each of the many tones simultaneously emitted by an orchestra, and can even follow the weaker tones of one instrument apart from the other sounds, of which the impressions being not attended to, are less vividly perceived. So, also, if one endeavors to direct attention to the whole field of vision at the same time, nothing is seen distinctly; but when the attention is directed first to this, then to that part, and analyzes the detail of the sensation, the part to which the mind is directed is perceived with more distinctness than the rest of the same sensation.

THE SENSE OF SMELL.

The sense of smell ordinarily requires for its excitement to a state of activity, the action of external matters which produce certain changes in the olfactory nerve; and this nerve is susceptible

may produce an acrid and burning
touch; but the sensation of odor is
these, though it may be simultaneo
condition of smell is a peculiar modi
a peculiar change produced in it
substance.

The material causes of odors are, i
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sion in the atmosphere; or gaseous exh
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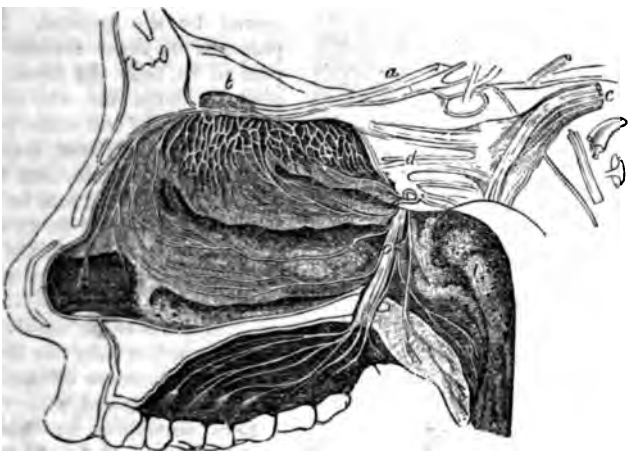
sense of smell itself. In fishes, the od
in the water; but in what form—whet
manner as the gases absorbed by water—
of odors must, in all cases, be dissolved i
membrane before they can be immediate
olfactory nerves; therefore, a further c
perception of odors is, that the mucou
cavity be moist. When the Schneideri
sense of smell is lost; in the first stage
tion of mucus within the nostrils is le
ceiving odors is either lost or rendered v

In animals living in the air, it is also
matter should be transmitted in a curr
This is effected by the respiratory mo
voluntary influence over the sense of s
respiration, we prevent the perception
quick inspirations, assisted, as in the
traction of

olfactory nerves retain much of the same soft and grayish texture which distinguishes their trunks (as the olfactory lobes of the brain are called) within the cranium. Their individual filaments, also, are peculiar, more resembling those of the sympathetic nerve than the filaments of the other cerebral nerves do, containing no outer white substance, and being finely granular and nucleated.[1] (Fig. 86.) The branches are distributed principally in close plex-

Fig. 85.

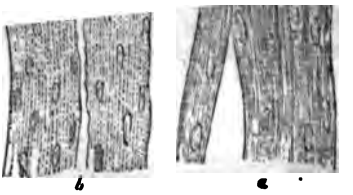


Outer wall of the nasal fossa, with the three spongy bones and meatus: the nerves being shown as they would appear through the membrane if it were transparent. *a*. Olfactory process. *b*. Olfactory bulb (represented rather too short) resting on the cribriform plate. Below is seen the plexiform arrangement of the olfactory filaments on the upper and middle spongy bones. *c*. Fifth nerve within the cranium with its Gasserian ganglion. *d*. Its superior maxillary division, sending branches to Meckel's ganglion, and through that to the three spongy bones, where they anastomose with the olfactory filaments, and with *s*, branches of the nasal division of the ophthalmic nerve. *o*. Posterior palatine twigs from Meckel's ganglion, supplying the soft and hard palate. *f*. Orifice of the Eustachian tube on the side of the pharynx, behind the lower spongy bone.—From Sœmmering, two-thirds diameter.

uses; but the mode of termination of the filaments is wholly unknown.

The sense of smell is derived exclusively through those parts of the nasal cavities in which the olfactory nerves are distributed; the accessory cavities or sinuses communicating with the nostrils

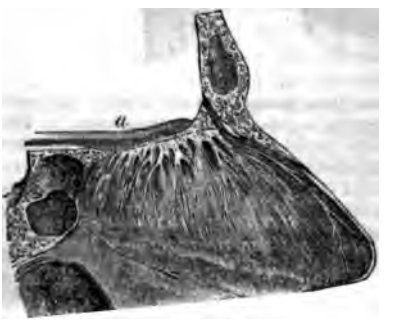
[1] See Todd and Bowman (xxxix. p. 396, Am. Ed.): the work which, before all, on the minute anatomy of the organs of sense, the student should consult.



Olfactory filaments of the dog: *a*. In water. *b*. In acetic acid.—Magnified 250 diameters.

ing. The former purpose, which is i
filling their cavities with fat, is here
bones of birds, by their being filled with

Fig. 87.



This is the case particularly with the sensations excited in the nose by acrid vapors, as of ammonia, horseradish, and mustard, &c., which resemble much the sensations of the nerves of touch; and the difficulty is the greater when it is remembered that these acrid vapors have nearly the same action upon the mucous membrane of the eyelids. It was because the common sensibility of the nose to these irritating substances remained after the destruction of the olfactory nerves, that Magendie was led to believe the fifth nerve might exercise the special sense.

Animals do not all equally perceive the same odors; the odors perceived by an herbivorous animal and by a carnivorous animal are different. The Carnivora have the power of detecting most accurately, by the smell, the special peculiarities of animal matters, and of tracking other animals by the scent; but have, apparently, no sensibility to the odors of plants and flowers. Herbivorous animals are peculiarly sensitive to the latter, and have a narrower sensibility to animal odors, especially to such as proceed from other individuals than their own species. Man is far inferior to many animals of both classes in respect of the acuteness of smell; but his sphere of susceptibility to various odors is more uniform and extended. The cause of this difference must lie in the endowments of the central parts of the olfactory apparatus.

Opposed to the sensation of an agreeable odor, is that of a disagreeable or disgusting odor, which corresponds to the sensations of pain, dazzling and disharmony of colors, and dissonance in the other senses. The cause of this difference in the effect of different odors is unknown; but this much is certain, that odors are pleasant or offensive in a relative sense only, for many animals pass their existence in the midst of odors which to us are highly disagreeable. A great difference in this respect is, indeed, observed amongst men: many odors generally thought agreeable, are to some persons intolerable; and different persons describe differently the sensations that they severally derive from the same odorous substances. There seems also to be in some persons, an insensibility to certain odors, comparable with that of the eye to certain colors; and among different persons, as great a difference in the acuteness of the sense of smell as among others in the acuteness of sight. We have no exact proof that a relation of harmony and disharmony exists between odors as between colors and sounds; though it is probable that such is the case, since it certainly is so with regard to the sense of taste; and since such a relation would account in some measure for the different degrees of perceptive power in different persons; for, as some have no ear for music (as it is said), so others have no clear appreciation of the relations of odors, and, therefore, little pleasure in them. It is also not cer-

...on that sensation of odour continue after the impression of the odorous matter has ceased, though we can scarcely imagine that such is not the case. It is difficult to ascertain this point by direct observation; because the odor that is frequently retained in the nose, may arise from some of the odorous matter remaining dissolved in the mucus of the nostrils.

The sensations of the olfactory nerves, independent of the external application of ... have hitherto been little studied. It has been ... grains of inodorous substances, such as salts, ... odor when injected into the nostrils. The ... machine is, however, known to produce a ... sephorus. Ritter, too, has observed, that when ... lied to the organ of smell, ... tickling sensation excited in the filaments of ... l like that of ammonia was excited by the negative ... il odor by the positive pole; whichever of these sensations was produced, it remained constant as long as the arch was closed, and changed to the other at the moment of the arch being opened. Frequently, a person smells something which is not present, and which other persons cannot ... This ... with nervous people, but it occasionally ... In a man who was constantly conscious of ... the ... was found, after death, by MM. Cullerier ... to be beset with deposits of bone: and in the middle ... the ... membranes were serious cysts in the state of ... Hawkins was acquainted with a man who, ever after a ... in the nose, which occurred several years before his death, ...

THE SENSE OF SIGHT.

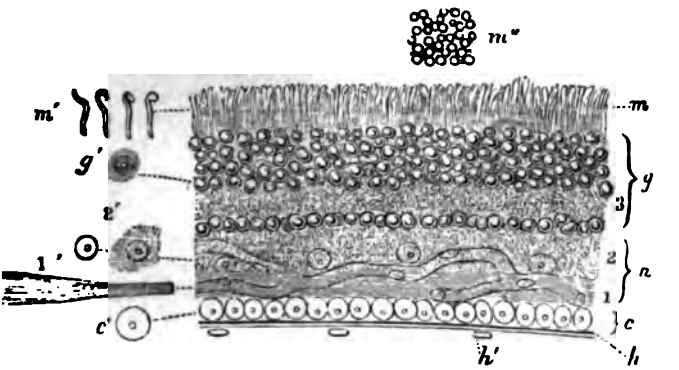
The eye, or the organ of vision, consists essentially in a membranous expansion of the peripheral extremity of the nerve of sight, the optic, for the purpose of receiving the impressions of the rays of light from luminous bodies. This expansion of the optic nerve is termed the *retina*. It is a delicate membrane, concave, with the concavity directed forwards; semi-transparent when fresh, but soon becoming clouded and opaque, with a pinkish tint from the blood in its minute vessels. It results from a sudden spreading out or expansion of the optic nerve, of whose terminal fibres, apparently deprived of their external white substance, it is almost entirely composed. At first, the fibres of the optic nerve run in distinct bundles, which radiate from the point at which the trunk of the nerve terminates, and then pursue a tolerably straight course towards the anterior margin of the retina. As they proceed in this course, however, the bundles shortly break up into their component

es, which then interlace and form a fine membranous sheath, ards the anterior margin of which all trace of fibrous arrange- nt disappears.

The mode in which the nerve-fibres of the retina terminate, is l involved in obscurity, in spite of the many efforts to determine question. Several observers, including Valentin, Bidder, and ppenheim, are of opinion that the fibres terminate in loops at the erior margin of the retina: Krause says he has observed these ps at every part of the retina, both in front and behind; whilst nnover states that the fibres end in free extremities, but never loops. Nothing, therefore, can at present be stated positively this point, except that at the posterior part of the retina, where sense of sight is especially developed, no nerve-terminations, ped or otherwise, have yet been found (except by Krause), and it, therefore, the opinion that each sensitive point of the retina responds to the extremity of a separate nerve-fibre is not founded fact.

Nearly all who have recently examined the minute structure of retina, concur in describing the existence of numerous cells and bules lying on both sides of the fibrous expansion of this mem- ne, and chiefly along its internal surface and within the meshes med by the interlacing of the individual nerve-fibres. These lular bodies appear to be of different kinds, although, as Henle

Fig. 88.



ertical section of the human retina and hyaloid membrane. *h*. Hyaloid membrane. *h'*. cle on its inner surface. *c*. Layer of transparent cells, connecting the hyaloid and retina. Separate cell enlarged by imbibition of water. *n*. Gray nervous layer, with its capillaries. 1. fibrous lamina. 2. Its vesicular lamina. 1'. Shred of fibrous lamina detached. 2'. icle and nucleus detached. *g*. Granular layer. 3. Light lamina frequently seen. *g'*. ached nucleated particle of the granular layer. *m*. Jacob's membrane. *m'*. Appearances ta particles, when detached. *m''*. Its outer surface. Magnified 320 diameters.

observes, it is probable that the several varieties met with are only the same cells in different stages of development. The larger and more perfectly developed cells are nearest to the fibrous layer (Fig. 88). By Valentin (xxxiv. 1837, p. 25), who first accurately described them, they were considered as identical with the ganglion-corpuscles of nervous substance: but Henle (xxxvii. p. 665) is of opinion that they probably constitute a kind of transparent epithelium, which serves to invest the delicate nerves composing the fibrous layer. Very shortly after death these cells break up, and the place which they occupied becomes a confused granular mass, in which are scattered, often in a linear direction, numerous oil-like globules, which are probably the nuclei of the disintegrated cells. Nothing has yet been found among them having any resemblance to caudate corpuscles giving origin, or affording a termination, to nerve-fibres.

Exactly in the centre of the retina, and at a point thus corresponding to the axis of the eye, in which the sense of vision is most perfect, is a round yellowish elevated spot, about 1-24th of an inch in diameter, having a minute aperture at its summit, and called after its discoverer the *yellow spot of Sœmmering* (Fig. 89). It is not covered by the fibrous part of the retina, but a layer of closely-set cells is said to pass over it (xxxix. p. 415, Am. Ed.) The use of this spot is quite unknown. At about an eighth of an inch to the inner side of the yellow spot, and consequently of the axis of the eye, is the point at which the optic nerve spreads out

Fig. 89.

Fig. 90.

Fig. 89. The yellow spot of the retina occupying the axis of the eye; and the entrance of the optic nerve, with the arteria centralis retinæ on the inner side of the axis.—After Sœmmering.

Fig. 90. Outer surface of the retina, showing the membrane of Jacob, partially detached. —After Jacob.

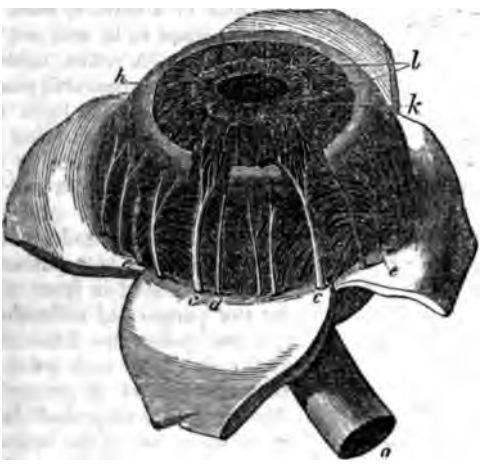
its fibres to form the retina. This is the only point of the surface of the retina from which the power of vision is absent.

On the outside, the retina is surrounded by the *membrana Ja-*

obi (Fig. 90), composed of cylindrical, or staff-shaped, transparent, and highly refractive bodies, arranged perpendicularly to the surface of the retina, with their outer extremities imbedded, to a greater or less depth, in a layer of black pigment of the choroid coat. The only plausible suggestion which has been offered concerning the use of these bodies, is one by Brücke, who thinks it not unlikely that they may serve to conduct back to the sensitive portion of the retina, those rays of light which, having traversed that membrane, are not entirely absorbed by the black pigment of the choroid.

The choroid, which is the next tunic of the eye, and surrounds the membrana Jacobi, consists of a thin and highly vascular membrane, of which the internal surface is covered by a layer of black pigment-cells, in which, as just said, the staff-shaped bodies of the membrana Jacobi are imbedded (Fig. 91). The principal use of

Fig. 91.



Choroid and iris, exposed by turning aside the sclerotica: *c, c.* Ciliary nerves branching in the iris. *d.* Smaller ciliary nerve. *e, e.* Vasa vorticosa. *h.* Ciliary ligament and muscle. *i.* Converging fibres of the greater circle of the iris. *l.* Looped and knotted form of these near the pupil, with the converging fibres of the lesser circle of the iris within them. *o.* The optic nerve.—From Zinn.

the choroid is to absorb, by means of its pigment, those rays of light which pass through the transparent retina, and thus to prevent their being thrown again upon the retina so as to interfere with the distinctness of the images there formed. Hence animals in which the choroid is destitute of pigment, and human Albinoes, are dazzled by daylight, and see best in the twilight.

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twofold manner capable of refracting and causing convergence of the rays of light that fall upon and traverse it. It thus affects them, first, by its density; for it is a law in optics that when rays of light pass from a rarer into a denser medium, if they impinge upon the surface in a direction removed from the perpendicular, they are bent out of their former direction towards that of a line perpendicular to the surface of the denser medium; and, secondly, by its convexity—for it is another law in optics that rays of light impinging upon a convex transparent surface are refracted towards the centre, those being most refracted which are farthest from the centre of the convex surface.

Behind the cornea is a space containing a thin watery fluid, the *aqueous humor*, holding in solution a small quantity of chloride of sodium and extractive matter. The space containing the aqueous humor is divided into an anterior and posterior *chamber* by a membranous partition, *the iris*, to be presently again mentioned. The effect produced by the aqueous humor on the rays of light traversing it is not yet fully ascertained. Its chief use, probably, is that of enabling the cornea to maintain its proper convexity; and at the same time to furnish a medium in which the movements of the iris can take place.

Behind the aqueous humor and the iris, and imbedded in the anterior part of the medium next to be described, viz., the vitreous humor, is seated a doubly convex body, the *crystalline lens*, which is the most important refracting structure of the eye. (Fig. 93.) The structure of the lens is very complex. It consists essentially of fibres united side by side to each other, and arranged together in very numerous laminæ, which are so placed upon one another that when hardened in spirit the lens splits into three portions, in the form of sections, each of which is composed of superimposed concentric laminæ. (Fig. 94.) The lens increases in density, and consequently in power of refraction, from without inwards; the central part, usually termed the nucleus, being the most dense. The density of the lens increases with age; it is comparatively soft in infancy, but very firm in advanced life: it is also more spherical at an early period of life than in old age.

The *vitreous humor* constitutes nearly four-fifths of the whole globe of the eye. It fills up the space between the retina and the lens, and its soft jelly-like substance consists essentially of numerous layers, formed of delicate, simple membrane, the spaces between which are filled with a watery, pellucid fluid. It probably exercises some share in refracting the rays of light to the retina; but its principal use appears to be that of giving the proper distension to the globe of the eye, and of keeping the surface of the retina at a proper distance from the lens.

Such are the transparent media by which the rays of light undergo the necessary refraction in their course from an external object to

Fig. 93. Position of the lens in the vitreous humor, dark triangular space on each side of the lens is intend of Petit.—After Arnold.

Fig. 94. Lens, hardened in spirit, and partially divid well as into lamellæ. Magnified 3¼ diameters.—After

investment, termed the *sclerotica*, whi
the contents of the eye, serves to give
muscles by which the movements of
These muscles, and the nerves supplying
considered (p. 347).

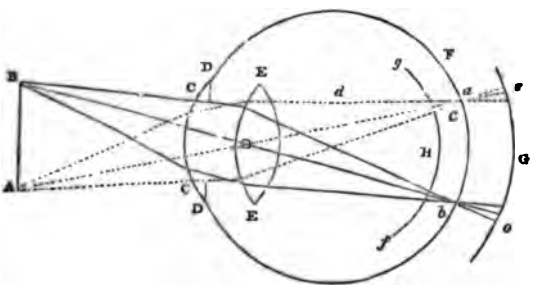
As already observed, the space occupi
is divided into two portions by a verticall
phragm, termed the *iris*, provided with a c
for the transmission of light. The iris is
bling those of contractile fibro-cellular tis
woven also a few organic muscular fibre
striped or animal muscular fibres. The fi
rection, for the most part, radiating from t
the pupil; but as they approach the pupil
a circular direction, and at the very edg
By the contraction of the radi
enlarged

Of the Phenomena of Vision.

The essential constituents of the optical apparatus of the eye may thus be enumerated: a nervous expansion, to receive and transmit to the brain the impressions of light; certain refracting media, for the purpose of so disposing of the rays of light traversing them as to throw a correct image of an external body on the retina; and a contractile diaphragm, with a central aperture, for regulating the quantity of light admitted into the eye.

With the help of the following diagram (Fig. 95), representing a vertical section of the eye from before backwards, the mode in which, by means of the refracting media of the eye, an image of an object of sight is thrown on the retina, may be rendered intelligible. The rays of the cones of light emitted by the points A B, and every other point of an object placed before the eye, are first refracted, that is, are bent towards the axis of the cone, by the cornea C C, and the aqueous humor contained between it and the lens. The rays of each cone are again refracted and bent still more towards its central ray or axis by the anterior surface of the lens E E; and again, as they pass out through its posterior surface into the less dense medium of the vitreous humor. For a lens has the power of refracting and causing the convergence of the rays of a cone of light, not only on their entrance from a rarer medium into its an-

Fig. 95.



terior convex surface, but also at their exit from its posterior convex surface into the rarer medium.

In this manner, the rays of the cones of light issuing from the points A and B are again collected to points at *a* and *b*; and, if the retina F be situated at *a* and *b*, perfect, though reversed, images of

Ophthalmic Surgery, by Mr. Bowman (lxxi. 1847 and 1848); Arnold (clxv.); Lawrence (clxxxv.); Wharton Jones (clxix. and lxxiii. art. *Eye*); and Brücke (clxx.).

... a corresponding po

The means by which *distinct* a formed in the retina, in the variou placed in relation to external obje under the following heads: 1, t tinctness from aberration; 2, the objects are viewed at different dis the *reversed image* of an object on right position by the mind.

1. Since the retina is concave, a margins gradually approaches the l of objects situated at the sides ca objects nearer to the middle of the f images are formed at a distance l sponding to the situation of the ret cone of light from an object situat vision do not meet all in the same refraction; for the refraction of the circumference of a lens is greater tha central portion. The concurrence of cause indistinctness of vision, unless Such correction is effected, in both c a kind of annular diaphragm to cover and to prevent the rays from passing but its centre, which corresponds to t

The image of an object will be m the pupil is narrow, the object at the the light abundant ...

Distinctness of vision is further secured by the inner surface of the choroid, immediately external to the retina itself, as well as the posterior surface of the iris and the ciliary processes, being coated with black pigment, which absorbs any rays of light that may be reflected within the eye, and prevents their being thrown again upon the retina, so as to interfere with the images there formed. The pigment of the choroid is especially important in this respect; for the retina is very transparent, and if the surface behind it were not of a dark color, but capable of reflecting the light, the luminous rays which had already acted on the retina would be reflected back again through it, and would fall upon other parts of the same membrane, producing both dazzling from excessive light, and indistinctness of the images.

In the passage of light through an ordinary convex lens, decomposition of each ray into its elementary colored parts commonly ensues, and a colored margin appears around the image, owing to the unequal refraction which the elementary colors undergo. In the optical instruments this, which is termed *chromatic aberration*, is corrected by the use of two or more lenses, differing in shape and density, the second of which continues or increases the refraction of the rays produced by the first, but by recombining the individual parts of each ray into its original white light, corrects any chromatic aberration which may have resulted from the first. It is probable that the unequal refractive power of the transparent media in front of the retina, may be the means by which the eye is enabled to guard against the effect of chromatic aberration. The human eye is achromatic, however, only so long as the image is received at its focal distance upon the retina, or so long as the eye adapts itself to the different distances of sight. If either of these conditions be interfered with, a more or less distinct appearance of colors is produced.

2. The distinctness of the image formed upon the retina is mainly dependent on the rays emitted by each luminous point of the object being brought to a perfect focus upon the retina. If this focus occurs at a point either in front of, or behind the retina, indistinctness of vision ensues, with the production of a halo. The focal distance, *i. e.*, the distance of the point at which the luminous rays from a lens are collected, besides being regulated by the degree of convexity and density of the lens, varies with the distance of the object from the lens, being greater as this is shorter, and *vice versâ*. Hence, since objects placed at various distances from the eye can, within a certain range, different in different persons,[1] be seen with

[1] An ingenious instrument for measuring the distances at which each person may have distinct sight of objects has been invented by Mr. Smee, who names it the Optometer (clxxxvi.).

cornea or lens; or, by changin
or of the lens, so that whether the
and the focal distance thus increas
to which the rays are converged b
place occupied by the retina. The a
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For, from the refractive powers of t
calculated by Olbers that the differ
of the images of an object at such
allel, and of one at the distance of 1
of an inch. On this calculation, th
retina from the lens required for vis
the cornea and lens to maintain the
than about one line, which might be
of the eye, or by a change in the pos
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axis of the eye. Olbers also calcul
the convexity of the cornea which w
vision at different distances, and fin
though greater than it appeared prob
power of the eye or of its muscles.

Both the above conditions, as well
supposed sufficient alone to account f
the eye. Thus, by Sir E. Home, and
exclusively to a change in the conv
by the muscles of the eyeball. Bu
showed that the necessary change wa
duced by the muscles of

Moreover, as observed by Volkmann, we do not seem to possess sufficient power over the recti muscles to produce the combined action of all the four at one time; and except by such combined action, either of all four, or at least of two opposite ones, retraction of the eyeball could not be effected. Injury of the third pair of nerves, also, whereby paralysis of three of the recti muscles is produced, is not followed by any material disturbance of the power of adaptation; and evidence has been furnished by Hueck to show that neither the oblique nor straight muscles can in any way exercise sufficient pressure on the eye to effect appreciable alteration in its form, or in the distinctness of an image formed on the retina.

The movements of the iris have been considered the means of adaptation by some physiologists, chiefly from the fact that when distant objects are viewed, the pupil becomes dilated; when near objects, contracted. In general, such movements in the iris might be regarded as merely associate movements, the pupil contracting when the eye is turned inwards, as in the act of looking at a near object, and dilating when the eyes are turned outwards. But contraction of the pupil may ensue when by a voluntary effort, without any change in the position of the axes of the eyes, a near object is regarded; and dilatation of the pupil when a distant object is regarded. The iris may therefore co-operate for the production of distinct vision at different distances; but sufficient evidence that it is not the chief organ for the adaptation, is furnished by the fact that individuals in whom the iris is wholly wanting may have perfect vision for near as well as distant objects. Hueck also states that, without altering the direction of the axes of his eyes or the quantity of light admitted, but merely by fixing his attention on a side object, he was able to widen his pupils as much as one-half more than their former diameter, without there ensuing any indistinctness of the object towards which the eyes were directed.

The opinion now most commonly entertained of the adapting power of the eye, is, that it is mainly due to some alteration either in position or form, or in both, undergone by the crystalline lens. The arguments stated by Hueck in favor of this view, are, first, that if the eye is watched attentively from the side, the iris will be observed to be bent forwards in the middle, and approximated closer to the cornea, when a near object is viewed, and to become flattened again when the sight is fixed upon a distant object: secondly, that when the fresh eye of a dog is removed and placed before a window, so that, through an opening in the sclerotica, a distinct image of the window-frame, and an indistinct one of a smaller object, such as a key, held nearer to the eye, are perceived, the latter may be rendered distinct and the former indistinct by drawing the lens forward with a needle, inserted through the margin of the cornea.

With respect to the mode in which such an approximation of the lens towards the cornea during the vision of near objects may be effected, different explanations are offered. By some it is supposed to be produced by vascular turgescence of the ciliary processes; the recedence of the lens ensuing on the cessation of the turgescence. By others, and with greater probability, it is supposed to be effected by the contraction of muscular tissue situated in the neighborhood of [illegible] and processes.[1] [An examination of the diagram [illegible] show that the action of the ciliary muscle must hav[illegible] vancing the ciliary processes, and with them the lens [illegible] rnea. The muscular nature of their structure is con[illegible] natomy in birds, where it is largely developed. Its [illegible] he striped variety, and are supplied with nerves fr[illegible]

That this muscle is [illegible] lapting the eye to distances seems proved by the fi[illegible] er is lost by the application of belladonna, by which [illegible] paralyzed, and from the circumstance that after the operation for cataract the adapting power also disappears. When the eye is employed in the examination of near objects, the pupil contracts, as do also the internal recti, and by the action of the ciliary muscles the lens is drawn forwards; all of which actions are performed by the influence of the third pair. The feeling of fatigue that is experienced under these circumstances is familiar to all, and arises from the effort made by the muscle above named. Whilst in the examination of distant objects, no such feelings are experienced, the lens retiring to the condition of repose, where it is maintained without muscular effort.]

Fig. 96.

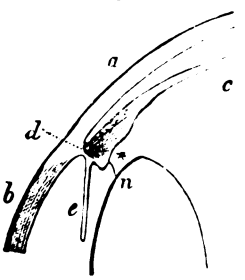


Diagram to show the position and action of the ciliary muscle: *a*. Sclerotic. *b*. Cornea. *c*. Choroid, separated a little from the sclerotic. *d*. Situation of the ciliary ligament, and point from which the ciliary muscle radiates. *e*. Iris. *n*. Lens, connected with the ciliary processes by the anterior wall of the canal of Petit, the situation of which is marked by the *. Magnified 3 diameters.

This view is supported by the fact that the adapting power of the eye can by many persons be exerted, and often rapidly, by a voluntary effort, quite independent of any alteration in the direction of the axes of the eyes; for it is inconceivable how such an effect can be produced, except by muscular fibres.

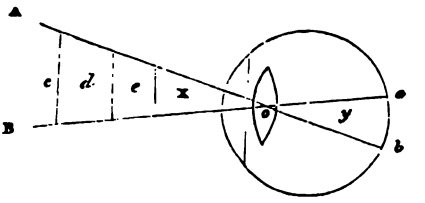
The observations of Volkmann and Hueck, and others, are also favorable to this view, since they show that in its quiescent state the eye is adapted to the vision of objects situated at the furthest

[1] For an analysis of the various opinions on this subject, consult the Supplement to Müller's Physiology.

point of distinct sight, and that, therefore, in order to accommodate itself to the vision of an object placed at any distance within this far point; the eye will require but one act, that, namely, of increasing its focal distance in proportion to the nearness of the object under view: an act of which the mind seems conscious by the effort which it has to make in adapting the eye to the vision of near objects. No act is requisite to adapt the eye to the perception of distant objects, for in reverting to its state of rest, it at once resumes its capacity for distant vision, and retains it so long as its quiescent state continues.

The range of distances through which persons can adapt their power of vision is not in all cases the same. Some persons possess scarcely any power of adaptation, and of this defect of vision there are two kinds: one, in which the person can see objects distinctly only when brought close to the eye, having little power to discern distant objects: another, in which distant objects alone can be distinctly perceived, a small body being almost invisible except when held at a considerable distance from the eye. In the one case the person is said to be short-sighted, or myopic: in the other, long-sighted or presbyopic. Myopia is caused by anything, such as undue convexity of the cornea, which increases the refracting power of the eye, and so causes the image of an object to be formed at a point anterior to the retina: the defect is remedied by the use of concave glasses. Presbyopia, or longsightedness, is the result of conditions the reverse of the above, and is remedied by the use of convex glasses, which diminish the focal distance of an image formed in the eye.[1]

Fig. 97.



3. The direction given to the rays by their refraction is regulated by that of the central ray, or axis of the cone, towards which the other rays are bent. The image of any point of an object is therefore, as a rule (the exceptions to which need not here be stated), always formed in a line identical with the axis of the cone of light, as in the line B a, or A b, Fig. 97: so that the spot where the image of any point will be formed upon the retina may be determined by prolonging the central ray of the cone of light, or that ray which traverses the centre of the pupil. Thus, A b is the axis or central ray of the cone of light

[1] For details on this subject, consult Müller (xxxii.), and the various treatises on the Physiology and Defects of Vision.

...ed at the bottom of the eye.
any albino animal, such as a whit
from the absence of pigment, are tr
and held with the cornea towards a
of the window completely inverted is
translucent wall of the eye. Volkm
has also shown that a similar experim
formed in a living person possessed o
an unusually transparent sclerotica.

No completely satisfactory explanati
account for the mind being able to form
position of an object of which an inver
retina. Müller and Volkmann are of o
perceives an object as inverted but need
thing is seen alike inverted, and the rels
therefore remains unchanged; and the
have of the inversion is by experiment a
optics. It is the same thing as the dail
sequent on the revolution of the entire e
by observing the position of the stars;
within twenty-four hours, that which wa
stars, comes to be above. Hence it is
arises between the sensations of inverted
which perceives everything in its erect p
all objects, even of our own limbs, in the r
and therefore maintain the same relative
of our hand, while used in touch, is seen
which we see objects —

co-operation of the mind in the several other parts of the act of vision. To these belong not merely the act of sensation itself, and the perception of the changes produced in the retina, as light and colors, but also the conversion of the mere images depicted in the retina into ideas of an extended field of vision, of proximity and distance, of the form and size of objects, of the reciprocal influence of different parts of the retina upon each other, the simultaneous action of the two eyes, and some other phenomena.

To speak first of the *ideal size of the field of vision*.—The actual size of the field of vision depends on the extent of the retina, for only so many images can be seen at any one time as can occupy the retina at the same time; and thus considered the retina, of which the affections are perceived by the mind, is itself the field of vision. But to the mind of the individual the size of the field of vision has no determinate limits; sometimes it appears very small, at another time very large; for the mind has the power of projecting the images on the retina towards the exterior. Hence the mental field of vision is very small, when the sphere of the action of the mind is limited by impediments near the eye; on the contrary, it is very extensive when the projection of the images on the retina towards the exterior by the influence of the mind is not impeded. It is very small, when we look into a hollow body of small capacity held before the eyes; large, when we look out upon a landscape through a small opening; more extensive when we look at the landscape through a window; and most so when our view is not confined by any near object. In all these cases, the idea which we receive of the size of the field of vision is very different, although its absolute size is in all the same, being dependent on the extent of the retina. Hence it follows that the mind is constantly co-operating in the acts of vision, so that at last it becomes difficult to say what belongs to mere sensation, and what to the influence of the mind.

By a mental operation of this kind, we obtain a correct idea of the size of individual objects, as well as of the extent of the field of vision. To understand this, it will be necessary to refer again to Fig. 97, page 425.

The angle x, included between the decussating central rays of two cones of light issuing from different points of an object, is called the optical angle—angulus opticus seu visorius. This angle becomes larger, the greater the distance between the points A and B; and since the angles x and y are equal, the distance between the points a and b in the image on the retina increases as the angle x becomes larger. Objects at different distances from the eye, but having the same optical angle, x—for example, the objects, c, d, and e—must also throw images of equal size upon the retina; and,

depicted on the retina, angle x, is therefore conceived by two miles, perhaps, if we know th infer it to be so from the numbe same time. And in the same wa different objects, viewed under the s mind to have a different size in th field of vision, which has always th preted by the mind as of extremely reason also, the image viewed in the a real landscape—as the true field of image depicted upon paper. The sa to the idea of depth in the field of vi our mind principally by the circums move forwards, different images in su our retina, so that we seem to pass bet the mind is the same thing as passing selves.

The action of the sense of vision in re therefore, quite different from that of objects of the latter sense are immediate body, with which they come into cont size. The part of a table touched by t the part of the hand receiving an impr our body in which a sensation is exci which we judge of the magnitude of t vision, on the contrary, the images of the objects themselves

images fall upon the same parts of the retina lie in the same visual direction; and when, by the action of the mind, the images or affections of the retina are projected into the exterior world, the relation of the images to each other remains the same.

The estimation of the *form of bodies* by sight is the result partly of the mere sensation, and partly of the association of ideas. Since the form of the images perceived by the retina depends wholly on the outline of the part of the retina affected, the sensation alone is adequate to the distinction of only superficial forms from each other, as of a square from a circle. But the idea of a solid body, as a sphere or a body of three or more dimensions, *e. g.*, a cube, can only be attained by the action of the mind constructing it from the different superficial images seen in different positions of the eye with regard to the object; and as shown by Mr. Wheatstone, from two different perspective projections of the body being presented simultaneously to the mind by the two eyes. Hence, when in adult age sight is suddenly restored to persons blind from infancy, all objects in the field of vision appear at first as if painted flat on one surface; and no idea of solidity is formed until after long exercise of the sense of vision combined with that of touch.

We judge of the *motion* of an object, partly from the motion of its image over the surface of the retina, and partly from the motion of our eyes following it. If the image upon the retina moves while our eyes and our body are at rest, we conclude that the object is changing its relative position with regard to ourselves. In such a case the movement of the object may be apparent only, as when we are standing upon a body which is in motion, such as a ship. If, on the other hand, the image does not move with regard to the retina, but remains fixed upon the same spot of that membrane, while our eyes follow the moving body, we judge of the motion of the object by the sensations of the muscles in action to move the eye. If the image moves over the surface of the retina while the muscles of the eye are acting at the same time in a manner corresponding to this motion, as in reading, we infer that the object is stationary, and we know that we are merely altering the relation of our eyes to the object. Sometimes the object appears to move when both object and eye are fixed, as in vertigo.

The mind can, by the faculty of *attention*, concentrate its activity more or less exclusively upon the senses of sight, hearing, and touch alternately. When exclusively occupied with the action of one sense, it is scarcely conscious of the sensations of the others. The mind, when deeply immersed in contemplations of another nature, is indifferent to the actions of the sense of sight, as of every other sense. We often, when deep in thought, have our eyes open and fixed, but see nothing, owing to the action of the fibres of the

principal subject of mental contem
matical figure produces a differe
attention is directed exclusively t
Thus, in Fig. 98, we may in succes
the whole, or of distinct parts only
outer circle, of the hexagon in the
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figure is composed, the more scope d
attention. Hence it is that archit
livening effect on the sense of visio
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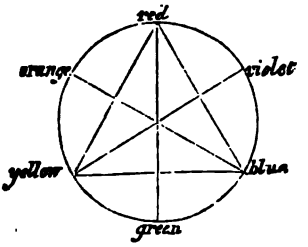
The *duration of the sensations* of t
that of the impressions which produc
the sensation persists 0.32 to 0.35 of
has ceased; and the duration of the q
greater in a direct ratio with the dura
caused it. Hence the image of a br
of a window through which the light
in the retina for a considerable period
our eye fixed for some time on them.

The color of the spectrum varies w
produced it. The spectra left by the
objects are ordinarily white or luminо
are dark. Sometimes, however, the r
parts in the image may, under certai
in the spectrum; what was bright may
may appear light. This occur
of the

objects upon the retina are always colored; and their color is, not that of the object, or of the image produced directly by the object, but the opposite, or complemental color. The spectrum of a red

Fig. 99.

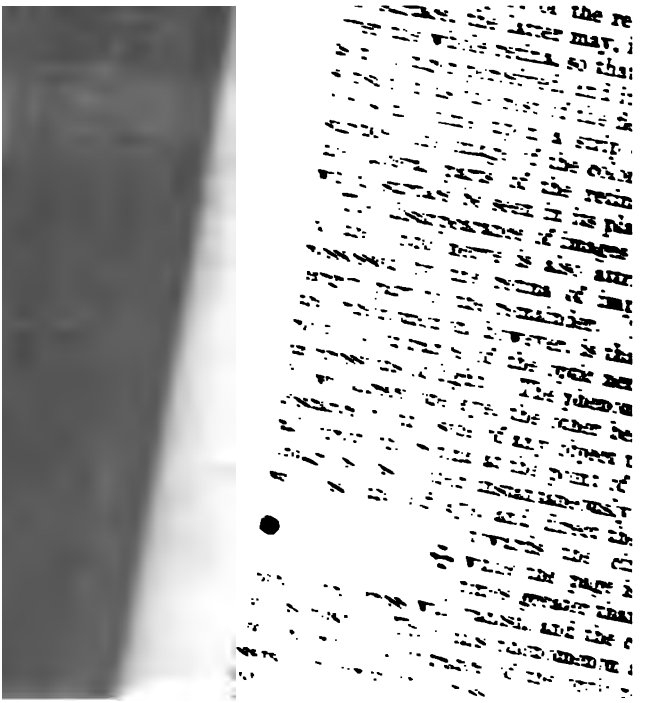


A circle showing the various simple and compound colors of light, and those which are complemental of each other, i. e., which, when mixed, produce a neutral gray tint. The three simple colors, red, yellow, and blue, are placed at the angles of an equilateral triangle, which are connected together by means of a circle; the mixed colors, green, orange, and violet, are placed intermediate between the corresponding simple or homogeneous colors; and the complemental colors, of which the pigments when mixed would constitute a gray, and of which the prismatic spectra would together produce a white light, will be found to be placed in each case opposite to each other, but connected by a line passing through the centre of the circle. The figure is also useful in showing the further shades of color which are complementary of each other. If the circle be supposed to contain every transition of color between the six marked down, those which when united yield a white or gray color, will always be found directly opposite to each other; thus, for example, the intermediate tint between orange and red is complemental of the middle tint between green and blue.

object is therefore, green; that of a green object, red; that of violet, yellow; that of yellow, violet, and so on. The colors which thus reciprocally excite each other in the retina are those placed at opposite points of the circle in Fig. 99.

Of the reciprocal action of different parts of the Retina on each other.

Although each elementary part of the retina represents a distinct portion of the field of vision, yet the different elementary parts, or sensitive points, of that membrane have a certain influence on each other; the particular condition of one influencing that of another, so that the image perceived by one part is modified by the image depicted in the other. The phenomena, which result from this relation between the different parts of the retina, may be arranged in two classes; the one including those where the condition existing in the greater extent of the retina is imparted to the remainder of that membrane; the other consisting of those in which the condition of the larger portion of the retina excites in the less extensive portion the opposite condition.



Thus, a very small dull-gray strip of paper, lying upon an extensive surface of any bright color, does not appear gray, but has a faint tint of the color which is the contrast of that of the surrounding surface (see page 431). A strip of gray paper upon a green field, for example, often appears to have a tint of red, and when lying upon a red surface, a greenish tint; it has an orange-colored tint upon a bright blue surface, and a bluish tint upon an orange-colored surface; a yellowish color upon a bright violet, and a violet tint upon a bright yellow surface. The color excited thus, as a contrast to the exciting color, being wholly independent of any rays of the corresponding color acting from without upon the retina, must arise as an opposite or antagonistic condition of that membrane; and the opposite conditions of which the retina thus becomes the subject would seem to balance each other by their reciprocal reaction. A necessary condition for the production of the contrasted colors is, that the part of the retina in which the new color is to be excited shall be in a state of comparative repose; hence the small object itself must be gray. A second condition is that the color of the surrounding surface shall be very bright, that is, it shall contain much white light.

Of the Simultaneous Action of the two Eyes.

Although the sense of sight is exercised by two organs, yet the impression of an object conveyed to the mind is single. Various theories have been advanced to account for this phenomenon. By Gall, it was supposed that we do not really employ both eyes simultaneously in vision, but always see with one only at a time. This especial employment of one eye in vision certainly occurs in persons whose eyes are of very unequal focal distance, but in the majority of individuals both eyes are simultaneously in action in the perception of the same object; this is shown by the double images seen under certain conditions. If two fingers be held up before the eyes, one in front of the other, and vision be directed to the more distant, so that it is seen singly, the nearer will appear double; while, if the nearer one be regarded, the more distant will be seen double; and one of the double images in each case will be found to belong to one eye, the other to the other eye.

Single vision results only when certain parts of the two retinæ are affected simultaneously; if different parts of the retinæ receive the image of the object, it is seen double. The parts of the retinæ in the two eyes which thus correspond to each other in the property of referring the images, which affect them simultaneously, to the same spot in the field of vision, are in man just those parts which would correspond to each other if one retina were placed exactly in front of, and over, the other (as in Fig. 100, c). Thus, the outer lateral portion of one eye corresponds to, or, to use a better term, is

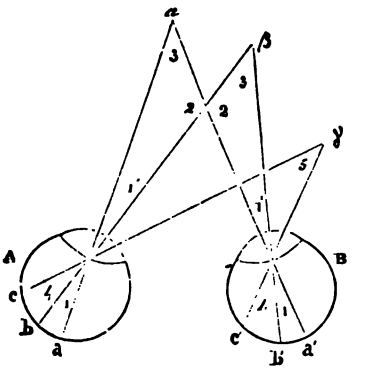
part of the ball of the eye, so as
luminous circle, seen at the opposit
on which the pressure is made. I
with the finger at the upper part o
of the other, two luminous circles
so also two figures are seen, when
on the two outer or the two inner si
therefore, that neither the upper pa
part of the other are identical, nor
two retinæ, nor their inner lateral
made with the fingers upon both eyes
part, one luminous ring is seen at th
the field of vision; if the pressure b
both eyes, a single luminous circle
field of vision below. So, also, if we
of the eye A, and upon the inner side
trum is produced, and is apparent at t
of vision; if upon the point *b* of one
other, a single spectrum is seen to the

The spheres of the two retina may t
one over the other, as in C, Fig. 100;
eye lies over the identical left portio
portion of one eye over the identical r
and so with the upper and lower por
over *a'*, *b* over *b'*, and *c* over *c'*. The
mediate between *a* and *c*, are
points of

and b' of the other, the distance of the two images a and b' will, inasmuch as a is identical with a', and b with b' lie at exactly the same distance from each other as images produced by impressions on the points a b of the one eye, or a' b' of the other.

In application of these results to the phenomena of vision, if the position of the eyes with regard to a luminous object be such that similar images of the same object fall on identical parts of the two retinæ, as occurs when the axes meet in some one point, the object is seen single; if otherwise, as in the various forms of squinting, two images are formed, and double vision results. If the axes of the eyes, A and B (Fig. 101), be so directed that they meet at a, an object at a will be seen singly, for the point a of the one retina, and a' of the other, are identical. So, also, if the object β be so situated that its image falls in both eyes at the same distance from the central point of the retina—namely, at b in the one eye, and at b' in the other—a will be seen single, for it affects identical parts of the two retinæ. The same will apply to the object δ.

Fig. 101.



In quadrupeds, the relation between the identical and non-identical parts of the retinæ cannot be the same as in man; for the axis of their eyes generally diverge, and can never be made to meet in one point of an object. When an animal regards an object situated directly in front of it, the image of the object must fall in both eyes on the outer portion of the retinæ. Thus the image of the object a (Fig. 102) will fall at a' in one eye, and at a'' in the other; and these points a' and a'' must be identical. So, also, for distinct and single vision of objects, b or c, the points b' and b'', or c' and c'', in the two retinæ, on which the images of these objects fall, must be identical. All points of the retina in each eye which receive rays of light from lateral objects only, can have no correspondent identical points in the retina of the other eye; for otherwise two objects, one situated to the right and the other to the left, would appear to lie in the same spot of the field of vision. It is probable, therefore, that there are in the eyes of animals parts of the retinæ which are identical, and parts which are not identical, *i. e.*, parts in one which have no corresponding parts in the other eye. And the relation of

the two retinæ to each other in the field of vision may be represented as in Fig. 103.

The cause of the impressions on identical points of the two retinæ giving rise to but one sensation, and the perception of a single

Fig. 102.

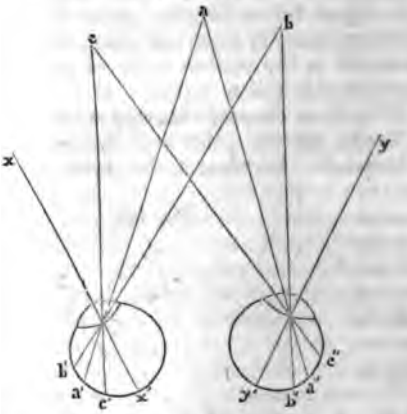


Fig. 103.

image, must either lie in the structural organization of the deeper or cerebral portion of the visual apparatus, or be the result of a mental operation; for in no other case is it the property of the corresponding nerves of the two sides of the body to refer their sensations as one to one spot.

Many attempts have been made to explain this remarkable relation between the eyes, by referring it to anatomical relations between the optic nerves. The circumstance of the inner portion of the fibres of the two optic nerves decussating at the commissure, and passing to the eye of the opposite side, while the outer portion of the fibres continue their course to the eye of the same side, so that the left side of both retinæ is formed from one root of the nerves, and the right side of both retinæ from the other root, naturally led to an attempt to explain the phenomenon by this distribution of the fibres of the nerves And this explanation is favored by cases in which the entire of one side of the retina, as far as the central point in both eyes, sometimes becomes insensible. But Müller shows the inadequateness of this theory to explain the phenomenon, unless it be supposed that each fibre in each cerebral portion of the optic nerves divides in the chiasma into two branches for the identical points of the two retinæ, as is shown in Fig. 104. But there is no foundation for such supposition.

By another theory, it was assumed that each optic nerve contains

ıe same number of fibres as the other, and that the cor-
ıt fibres of the two nerves are united in the sensorium (as

. 104.

Fig. 105.

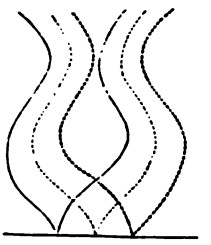
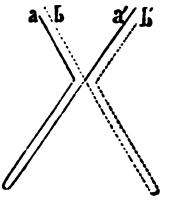
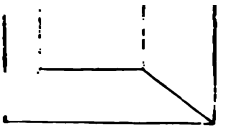


Fig. 106.



)5). But in this theory no account is taken of the partial
n of the fibres of the nerves in the chiasma.
ing to a third theory, the fibres *a* and *a′*, Fig. 106, coming
tical points of the two retina, are in the chiasma brought
ptic nerve, and in the brain either are united by a loop,
from the same point. The same disposition prevails in
f the identical fibres *b* and *b′*. According to this theory,
ılf of each retina would be represented in the left hemi-
the brain, and the right half of each retina in the right
e.
r explanation is founded on the fact that at the anterior
e chiasma of the optic nerve, certain fibres pass across
listal portion of one nerve to the corresponding portion
ıer nerve, as if they were commissural fibres forming a
ı between the retinæ of the two eyes. It is supposed,
at these fibres may connect the corresponding parts of
ıtinæ, and may thus explain their unity of action; in the
as corresponding parts of the cerebral hemispheres are
o be connected together by the commissural fibres of the
losum, and so enabled to exercise unity of function.
. the whole, it is more probable, that the power of forming
lea of an object from a double impression conveyed by
ye is the result of a mental act. This is supported by
facts as those by which the power has been shown by
Wheatstone to be subservient to the purpose of obtaining
reception of bodies raised in relief. When an object is
near the eyes that to view it the optic axis must converge,
perspective projection of it is seen by each eye, these
es being more dissimilar as the convergence of the optic
mes greater. Thus, if any figure of three dimensions,
cube, for example, be held at a moderate distance before



the right eye, and B that seen by
has shown that on this circumstan
our conviction of the solidity of an
relief. If different perspective dra
resenting the image seen by the rig
the left (for example, the drawings
presented to corresponding parts o
readily done by means of the *stereo*
by Professor Wheatstone for the pu
not merely a single representation of
jecting in relief, the exact counter
drawings were made.

SENSE OF HE

Anatomy of the Or

The organ of hearing is formed by
tory nerve within the *internal ear*, a
cavities within the petrous portion o
bone which forms the walls of these
around it, and forms the
the cavi

opening leading into the *cochlea*. The hinder part of the inner wall of the vestibule also presents an opening, the orifice of the

Fig. 108.

Interior of the osseous labyrinth. V. Vestibule. *a v.* Aqueduct of the vestibule. *o.* Fovea semiellíptica. *r.* Fovea hemispherica. S. Semicircular canals. *s.* Superior. *p.* Posterior. *i.* Inferior. *a a a.* The ampullar extremity of each. C. Cochlea. *ac.* Aqueduct of the cochlea. *sv.* Osseous zone of the lamina spiralis, above which is the scala vestibuli, communicating with the vestibule. *st.* Scala tympani below the spiral lamina.—From Sœmmering.

aquæductus vestibuli, a canal leading to the posterior margin of the petrous bone, with uncertain contents and unknown purpose.

The *semicircular canals* are six arched cylindriform bony canals, set in the substance of the petrous bone. They all open at both ends into the vestibule (two of them first coalescing). The ends of each are dilated just before opening into the vestibule; and one end of each being more dilated than the other is called an *ampulla*. Two of the canals form nearly vertical arches; of these the superior is also anterior; the posterior is inferior; the third canal is horizontal, and lower and shorter than the others.

The *cochlea*, a small organ, shaped like a common snail-shell, is seated in front of the vestibule, its base resting on the bottom of the internal meatus, where some apertures transmit to it the cochlear filaments of the auditory nerve. In its axis, the cochlea is traversed by a conical column, or *modiolus*, around which a *spiral canal* winds, with about two turns and a half from the base to the apex. At the apex of the cochlea the canal is closed; at the base it presents three openings, of which one, already mentioned, com-

municates with the vestibule; another, called *fenestra rotunda*, is separated by a membrane from the cavity of the tympanum; the third is the orifice of the *aquæductus cochleæ*, a canal leading to the jugular fossa of the petrous bone, and corresponding, at least in obscurity of purpose and origin, to the aquæductus vestibuli. The spiral canal is divided into two passages, or *scalæ*, by a partition of bone and membrane, the *lamina spiralis*. The osseous part or *zone* of this lamina, i[illegible] the modiolus; the membranous part, with a mu[illegible] ng its outer margin, is attached to the outer [illegible]. Commencing at the base of the cochlea, be[illegible] ad tympanic openings, they form a partition [illegible] es; the two scalæ are, therefore, in correspondence [illegible] cement, named *scala vestibuli* and *scala tym[illegible]* e cochlea, the lamina spiralis ends in a smal[illegible] concave part of which, being detached from the [illegible] olus, leaves a small aperture by which the two scalæ, [illegible] all the rest of their length, communicate.

Within the cavities now described is the *membranous labyrinth*, which corresponds generally with their form, but is separated from the walls of the vestibule and semicircular canals, except where the nerves enter into connection within it. The membranous labyrinth contains a fluid called *endolymph*; and between its outer surface and the inner surface of the walls of the vestibule and semicircular canals is another collection of similar fluid called *perilymph*; so that all the sonorous vibrations impressing the auditory nerves on these parts of the internal ear are conducted through fluid to a membrane suspended in and containing fluid. The fluid in the cochlea communicates with that in the vestibule, but there is no fluid external to its lining membrane.

The vestibular portion of the membranous labyrinth comprises two, probably communicating cavities, of which the upper and larger is named the *utriculus*; the lower the *sacculus*. In the former, open the orifices of the membranous semicircular canals. The membrane composing this labyrinth is laminated, transparent, very vascular, covered on both surfaces with nucleated cells; in the cavities which it incloses, especially in the utriculus and sacculus, it contains small masses of calcareous particles, named *otoconia* or *ear-powder*.

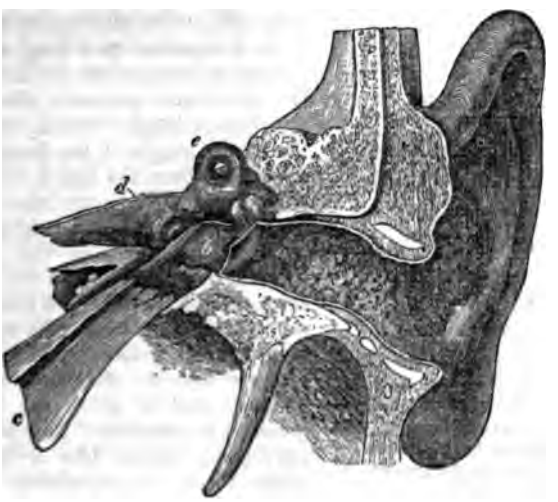
The *auditory nerve*, for the appropriate exposure of whose filaments to sonorous vibrations all the organs now described are provided, is characterized as a nerve of special sense by its softness (whence it derived its name of *portio mollis* of the seventh pair), and by the fineness of its component fibres. It enters the labyrinth of the ear in two divisions: one for the vestibule and semicircular

[1] A very minute description of the structure of the *lamina spiralis* and *cochlearis muscle* is given in Todd and Bowman, Am. ed.

canals, the other for the cochlea. The branches for the vestibule spread out and radiate on the inner surface of the membranous labyrinth, and appear to mingle with the calcareous powder: their termination is unknown. Those for the semicircular canals pass into the ampullæ, and form within each of them a bulging projection, in which, according to Wagner, they terminate in free loops. The branches for the cochlea enter it through orifices at the base of the modiolus, which they ascend, and thence successively pass into canals in the osseous part of the lamina spiralis. In the canals of this osseous part, or zone, the nerves are arranged in plexuses; and beyond them, entering the membranous part of the lamina, they terminate either in free extremities or in loops.

Such are the essential parts of the human organ of hearing. To these, others are adapted for the proper transmission of the sonorous vibrations of the air through, chiefly, the fenestra rotunda and the fenestra ovalis, the apertures by which the internal ear is separated by membrane alone from the cavity of the *tympanum* or *middle ear*. (Fig. 109.) The tympanum is an air cavity in the temporal bone, opening through its anterior and inner wall into the Eustachian tube, a cylindriform flattened canal, dilated at both ends, composed

Fig. 109.



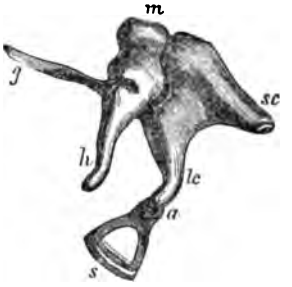
General view of the external, middle, and internal ear, as seen in a prepared section through *a*, the auditory canal. *b*. The tympanum or middle ear. *c*. Eustachian tube, leading to the pharynx. *d*. Cochlea: and *e*. Semicircular canals and vestibule, seen on their exterior, as brought into view by dissecting away the surrounding petrous bone. The styloid process projects below; and the inner surface of the carotid canal is seen above the Eustachian tube.—From Scarpa.

partly of bone and partly of cartilage, lined with mucous membrane and forming a communication between the tympanum and the pharynx. It opens into the cavity of the pharynx just behind the posterior aperture of the nostrils. The cavity of the tympanum communicates with the air-cavities in the mastoid process of the temporal bone; but its only opening to the external air is through the Eustachian tube. The walls of the tympanum are osseous, except where apertures in the bone are closed with membrane, as at the fenestra rotunda and fenestra ovalis, and at the outer part, where the bone is replaced by the *membrana tympani*. The cavity of the tympanum is lined with mucous membrane and ciliated epithelium continuous with those of the Eustachian tube. It contains a chain of small bones (*ossicula auditus*), extending from the membrana tympani to the fenestra ovalis.

The *membrana tympani* is placed in a slanting direction at the bottom of the external auditory canal, its plane being at an angle of about 45° with the lower wall of the canal. It is formed, chiefly, of a tough and tense fibrous membrane, the edges of which are set in a bony groove; its outer surface is covered with a continuation of the epidermal lining of the auditory canal, its inner surface, with part of the ciliated mucous membrane of the tympanum.

The *ossicles* of the ear are three, named *malleus*, *incus*, and *stapes*. (Fig. 110.) The *malleus*, or hammer-bone, is attached by a long, slightly-curved process, called its handle, to the membrana tympani; the line of attachment being vertical, including the whole length of the handle, and extending from the upper border to the centre of the membrane. The head of the malleus is irregularly rounded; its neck, or the line of boundary between it and the handle supports two processes; a *short* conical one, which receives the insertion of the *tensor tympani*, and a *slender* one, *processus gracilis*, which extends forwards, and to which the *laxator tympani* is attached. The *incus*, or anvil-bone, shaped like a bicuspid molar tooth, is articulated by its broader part, corresponding with the surface of the crown of a tooth, to the malleus. Of its two fang-like processes, one, directed backwards, has a free end; the other, curved downwards and more pointed, articu-

Fig. 110.



Ossicles of the left ear articulated, and seen from the outside and below. *m*. Head of the malleus, below which is the constriction, or neck. *g*. Processus gracilis, or long process, at the root of which is the short process. *h*. Manubrium, or handle. *sc*. Short crus; and *lc*, long crus of the incus. The body of this bone is seen articulating with the malleus, and its long crus, through the medium of the orbicular process, here partly concealed, *a*, with the stapes. *s*. Base of the stapes. Magnified three diameters.—From Arnold.

lates with the *stapes*, a little bone shaped exactly like a stirrup, of which the base or bar fits in the fenestra ovalis. To the neck of the stapes, a short process, corresponding with the loop of the stirrup, is attached the *stapedius* muscle.

The bones of the ear are covered with mucous membrane reflected over them from the wall of the tympanum; and are movable both altogether and one upon the other. The malleus moves and vibrates with every movement and vibration of the membrana tympani, and its movements are communicated through the incus to the stapes, and through it to the membrane closing the fenestra ovalis. The malleus, also, is movable in its articulation with the incus; and the membrana tympani moving with it is altered in its degree of tension by the laxator and tensor tympani muscles. The stapes is movable on the process of the incus, when the stapedius muscle acting draws it backwards.

The external ear consists of the *auricle* and external *auditory canal*. The principal parts of the auricle are two prominent rims inclosed one within the other (*helix* and *anthelix*), and inclosing a central hollow named the *concha;* in front of the concha, a prominence directed backwards, the *tragus*, and opposite to this one directed forwards, the *antitragus*. From the concha the auditory canal, with a slight arch directed upwards, passes inwards and a little forwards to the membrana tympani, to which it thus serves to convey the vibrating air. Its outer part consists of fibro-cartilage continued from the concha; its inner part of bone.

Physiology of Hearing.

The acoustic portion of the physiology of hearing is thus illustrated by Müller: chiefly in applications of the results of his experiments on the conduction of sonorous vibrations through various combinations of air, water, and solid substances, especially membranes.

All the acoustic contrivances of the organ of hearing are means for conducting the sound, just as the optical apparatus of the eye are media for conducting the light. Since all matter is capable of propagating sonorous vibrations, the simplest conditions must be sufficient for mere hearing; for all substances surrounding the auditory nerve would communicate sound to it. In the eye, a certain construction was required for directing the rays or undulations of light in such a manner that they should fall upon the optic nerve with the same relative disposition as that with which they issued from the object. In the sense of hearing this is not requisite. Sonorous vibrations, having the most various direction and the most unequal rate of succession, are transmitted by all media without modification, however manifold their decussations; and, wherever

these vibrations or undulations fall upon the organ of hearing and the auditory nerves, they must cause the sensation of corresponding sounds. The whole development of the organ of hearing, therefore, can have for its object merely the *rendering more perfect* the propagation of the sonorous vibrations, and their *multiplication* by resonance; and, in fact, all the acoustic apparatus of the organ may be shown to have reference to these two principles.

Functions of the External Ear.

The external auditory p… …ces the propagation of sound to the tympanum in th… inasmuch as the sonorous undulations, entering dir… atmosphere, are transmitted by the air in the passag… to the membrana tympani, and are prevented fro… …ed; 2, by the walls of the passage conducting the s… …tions imparted to the external ear itself, by the shorte… …ttachment of the membrana tympani, and so to this membrane; 3, by the resonance of the column of air contained within the passage.

As a conductor of undulations of air, the external auditory passage receives the direct undulations of the atmosphere, of which those that enter in the direction of its axis produce the strongest impression. The undulations which enter the passage obliquely are reflected by its parietes, and thus by reflexion reach the membrana tympani. By reflexion, also, the external meatus receives the undulations which impinge upon the concha of the external ear, when their angle of reflexion is such that they are thrown towards the tragus. Other sonorous undulations, again, which could enter the meatus from the external air neither directly nor by reflexion, may still be brought into it by inflexion; undulations, for instance, whose direction is that of the long axis of the head, and which pass over the surface of the ear, must, in accordance with the laws of inflexion, be bent into the external meatus by its margins. But the action of those undulations which enter the meatus directly are most intense: and hence we are enabled to judge of the point whence sound comes, by turning one ear in different directions, till it is directed to the point whence the vibrations may pass directly into the meatus, and produce the strongest impression.

The walls of the meatus are also solid conductors of sound; for those vibrations which are communicated to the cartilage of the external ear, and not reflected from it, are propagated by the shortest path through the parietes of the passage to the membrana tympani. Hence, both ears being close stopped, the sound of a pipe is heard more distinctly when its lower extremity, covered with a membrane, is applied to the cartilage of the external ear itself, than when it is placed in contact with the surface of the head.

Lastly, the external auditory passage is important, inasmuch as he air which it contains, like all insulated masses of air, increases he intensity of sounds by resonance. To convince ourselves of his, we need only lengthen the passage by affixing to it another ube: every sound that is heard, even the sound of our own voice, s then much increased in intensity.

The action of the cartilage of the external ear upon sonorous ribrations is partly to reflect them, and partly to condense and conduct them to the parietes of the external passage. With respect to its reflecting action, the concha is the most important part, since it directs the reflected undulations towards the tragus, whence they are reflected into the auditory passage. The other inequalities of the external ear do not promote hearing by reflection; and, if the conducting power of the cartilage of the ear were left out of consideration, they might be regarded as destined for no particular use; but receiving the impulses of the air, the cartilage of the external ear, while it reflects a part of them, propagates within itself and condenses the rest, as all other solid and elastic bodies would do. Thus, the sonorous vibrations which it receives by an extended surface, are conducted by it to its place of attachment. In consequence of the connection of the parietes of the auditory passage with the solid parts of the whole head, some dispersion of the undulations will result; but the points of attachment of the membrana tympani will receive them by the shortest path, and will as certainly communicate them to that membrane as the solid sides of a drum communicate sonorous undulations to the parchment head, or the bridge of a musical string its vibrations to the string.

Regarding the cartilage of the external ear, therefore, as a conductor of sonorous vibrations, all its inequalities, elevations, and depressions, which are useless with relation to reflexion, become of evident importance; for those elevations and depressions upon which the undulations fall perpendicularly, will be affected by them in the most intense degree; and, in consequence of the various form and position of these inequalities, sonorous undulations, in whatever direction they may come, must fall perpendicularly upon the tangent of some one of them. This affords an explanation of the extraordinary form given to this part.

Functions of the Middle Ear; the Tympanum, Ossicula, and Fenestræ.

In animals living in the atmosphere, the sonorous vibrations are conveyed to the auditory nerve by three different media in succession; namely, the air, the solid parts of the body of the animal and of the auditory apparatus, and the fluid of the labyrinth.

Sonorous vibrations are imparted too imperfectly from air to solid bodies, for the propagation of sound to the internal ear to be

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means of communicating in full
in the tympanum to the fluid
property of membranes is the
but of the elasticity and capabil
cles; and it is not impaired,
fenestra rotunda, they are not im

Sonorous vibrations are also c
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closed by membrane only, and th
stapes is connected—transmit very
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A small solid body, fixed in an o
membrane, so as to be movable,
tions, from air on one side, to wate
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fenestra ovalis, is by its other end
membrane, which has atmospheric

A tense membrane is a much bet
of air than any other solid body ho
the vibrations

vibrations are felt distinctly when the vibrating tuning fork is held over the membrane without touching it; but the wood alone, isolated from the membrane, will only very feebly propagate the vibrations of the air to the hand.

The ossicula of the ear, which are represented in this experiment by the piece of wood, are the better conductors of the sonorous vibrations communicated to them, on account of being isolated by an atmosphere of air, and not continuous with the bones of the cranium; for every solid body thus isolated by a different medium propagates vibrations with more intensity through its own substance than it communicates them to the surrounding medium, which thus prevents a dispersion of the sound; just as the vibrations of the air in the tubes used for conducting the voice from one apartment to another are prevented from being dispersed by the solid walls of the tube. The vibrations of the membrana tympani are transmitted, therefore, by the chain of ossicula to the fenestra ovalis and fluid of the labyrinth, their dispersion in the tympanum being prevented by the difficulty of the transition of vibrations from solid to gaseous bodies. The membrana tympani being a tense solid body bounded by free surfaces, the sonorous undulations will be partially reflected at its surfaces, so as to cause a meeting of undulations from opposite directions within it; it will therefore, by resonance, increase the intensity of the vibrations communicated to it, and the undulations thus rendered more intense will act in their turn upon the chain of auditory bones.

The oscillations of the membrana tympani as a whole, produced by very intense sounds, will, if the undulations of the air fall upon the membrane in a perpendicular direction, occupy its whole extent at once; but if the undulations of the air fall upon it obliquely, so as to strike one part of it before the rest, the movement of the membrane will commence at this point, and will thence extend to the other parts, like the oscillation which is excited near one extremity of a musical string, or at one limited part of the membrane of a drum. These oscillations, being reflected at the borders of the membrane, will traverse it to and fro. In consequence of the oblique position of the membrana tympani, this must always occur when the sonorous undulations enter the ear in the direction of the meatus auditorius externus—that is, in a direction parallel with its axis. When the sonorous undulations enter the meatus in any other direction, they will be reflected backwards and forwards by the walls of the passage; and it will depend on the angles at which they are reflected, in what manner, and at what point, they shall first strike upon the membrana tympani.

The propagation of the undulations of condensation and rarefaction, in which the smaller particles merely of the membrane move, is also modified in the same way by the mode in which the

neither would the vibrations c
chain of bones isolated, so as to
with concentration of their inten
the membrana tympani are readi
cavity of the tympanum, those
conducted away by the air, but w
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The propagation of sound throu
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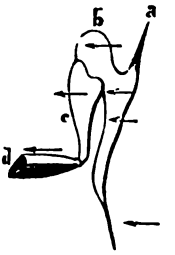
Fig. 111.



The long proce
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t of the undulation, which remains the same as it was in the
itus externus and long process of the malleus, so that the un-
ations are communicated by the stapes to the fenestra ovalis in
rpendicular direction.

ncreasing tension of the membrana tympani diminishes the
lity of transition of sonorous undulations from the air to it.
Savart observed that the dry membrana tympani, on the ap-
ch of a body emitting a loud sound, rejected particles of sand
wn upon it more strongly when lax than when very tense; and
rred, therefore, that hearing is rendered less acute by increas-
the tension of the membrana tympani. Müller has confirmed
by experiments with small membranes arranged so as to imi-
the membrana tympani: and it may be confirmed also by ob-
ation on one's self. For the membrana tympani in one's own per-
may be rendered tense at will in two ways; namely, by a strong
continued effort of expiration or of inspiration, while the mouth
nostrils are closed. In the first case, the compressed air is
ed with a whizzing sound into the tympanum, the membrana
pani is made tense, and immediately hearing becomes indistinct.
same temporary imperfection of hearing is produced by render-
the membrana tympani tense, and convex towards the interior,
he effort of inspiration. The imperfection of hearing, produced
the last-mentioned method, may continue for a time even after
mouth is opened, in consequence of the previous effort at inspira-
having induced collapse of the walls of the Eustachian tubes,
ch prevents the restoration of equilibrium of pressure between
air within the tympanum and that without: hence we have
opportunity of observing that even our own voice is heard
less intensity when the tension of the membrana tympani is
t.

f the pressure of the external air or atmosphere be very great,
le, on account of collapse of the walls of the Eustachian tube,
air in the interior of the tympanum fails to exert an equal
nter-pressure, the membrana tympani will of course be forced
ards, and imperfect deafness be produced. Thus it may be ex-
ned why, in a diving-bell, voices sound faintly. In all cases,
effect of the increased tension of the membrana tympani is not
ender both grave and acute sounds equally fainter than before.
the contrary, as observed by Dr. Wollaston, the increased tension
he membrana tympani produced by exhausting the cavity of the
panum, makes one deaf to grave sounds only.

he principal office of the Eustachian tube, in Müller's opinion,
relation to the prevention of these effects of increased tension
he membrana tympani. Its existence and openness will pro-
for the maintenance of the equilibrium between the air within
tympanum and the external air, so as to prevent the inordinate

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points, and by the crossing of these
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fluid of the labyrinth with much
medium of the chain of auditory bon
through the m[illegible]

ion is probably to be found in the following circumstances. The imate purpose of the organ of hearing is to impart, as perfectly possible, the impulses of the sonorous vibrations to the fibres of auditory nerve. This nerve being soft, and, like all nerves, regnated with water, sonorous undulations, if directly communited to it from solid parts, would be partly converted into undulons of a fluid, before producing their impression on the fibres. ides, however, the impregnation of the nervous fibres with water, which their softness depends, all the interspaces between the es are, as in all soft tissues, filled with fluid matters, either blood he fluid of cellular membrane. Hence the auditory nerve, in iving the sonorous undulations through the medium of the fluid he labyrinth, receives them from a medium of the same kind hat which occupies all the pores and interstices of the nervous es themselves. On this account, the vibration of the particles he nerve itself will probably be much more uniform in character n if the surfaces of the nerve had been in contact with solid parts; which case, the more internal particles of the nerve, being dist from the surface of the solid bone, would be acted on in a diffent manner from the more superficial particles.

The function usually ascribed to the *semicircular canals* is the lecting, in their fluid contents, the sonorous undulations from bones of the cranium. They have probably, also, in some ree, the power of conducting sounds in the direction of their ved cavities more easily than the sounds are carried off by the rounding hard parts in the original direction of the undulations, ugh this conducting power is in them much less perfect than in es containing air.

Admitting that they have these powers, the increased intensity the sonorous vibrations thus attained will be of advantage in ing on the auditory nerve where it is expanded in the ampullæ the canals, and in the utriculus. Where the membranous als are in contact with the solid parietes of the tubes, this action st be much more intense. But the membranous semicircular als must have a function independent of the surrounding hard ts; for in the Petromyzon, they are not separately inclosed in id substance, but lie in one common cavity with the utriculus.

The *crystalline pulverulent masses* in the labyrinth would reince the sonorous vibrations by their resonance, even if they did actually touch the membranes upon which the nerves are exded; but, inasmuch as these bodies lie in contact with the membnous parts of the labyrinth, and the vestibular nerve-fibres are bedded in them, they communicate to these membranes and the ves vibratory impulses of greater intensity than the fluid of the yrinth can impart. This appears to be the office of the otoconia.

Sonorous undulations in water are not perceived by the hand itself immersed in the water, but are felt distinctly through the medium of a rod held in the hand.

The *cochlea* seems constructed for the spreading out of the nervous fibres over a wide extent of surface, upon a solid lamina communicating with the solid walls of the labyrinth and cranium, at the same time that it is in contact with the fluid of the labyrinth; and which, besides exposing t[illegible]res to the influence of sonorous undulations by twc[illegible]f insulated by fluid on either side.

The connection of the[illegible]s with the solid walls of the labyrinth adapts the co[illegible]reception of the sonorous undulations propagated [illegible]s of the head and the walls of the labyrinth. The[illegible]byrinth of the vestibule and semicircular canals is [illegible]in the perilymph, and is destined more particular[illegible]ption of sounds through the medium of that fluid, whether the sonorous undulations are imparted to the fluid through the fenestræ, or by the intervention of the cranial bones, as when sounding bodies are brought into communication with the head or teeth. The spiral lamina on which the nervous fibres are expanded in the cochlea is, on the contrary, continuous with the solid walls of the labyrinth, and receives directly from them the impulses which they transmit. This is an important advantage; for the impulses imparted by solid bodies have, *cæteris paribus*, a greater absolute intensity than those communicated by water. And, even when a sound is excited in the water, the sonorous undulations are more intense in the water near the surface of the vessel containing it, than in other parts of the water equally distant from the point of origin of the sound; hence we may conclude that, *cæteris paribus*, the sonorous undulations of solid bodies act with greater intensity than those of water. Hence we perceive at once an important use of the cochlea.

This is not, however, the sole office of the cochlea; the spiral lamina, as well as the membranous labyrinth, receives sonorous impulses through the medium of the fluid of the labyrinth from the cavity of the vestibule and from the fenestra rotunda. The lamina spiralis is, indeed, much better calculated to render the action of these undulations upon the auditory nerve efficient than the membranous labyrinth is; for, as a solid body, insulated by a different medium, it is capable of resonance.

Lastly, it may be observed that the fibres of the nerve being spread out singly upon the lamina spiralis is advantageous, because, in the first place, it insures a more complete participation of the fibres in the impulses communicated by the solid parts of the cochlea; and, secondly, the intensity with which the sonorous un-

dulations are communicated to a body is proportionate to the extent of surface over which they can act on it.

Sensibility of the Auditory Nerve.

Most frequently, several undulations or impulses on the auditory nerve concur in the production of the impression of sound. But that a single impulse may be sufficient to excite the sensation, we have an example in the sound produced by an explosion or the sudden division of air, by the coming together of two previously separated bodies of air, as in cracking a whip, &c. There is, at all events, nothing to refute this opinion; although it must be admitted that a single shock to the air will very readily excite a succession of undulations.

By the rapid succession of several impulses at unequal intervals, a noise or rattle is produced: from a rapid succession of several impulses at equal intervals, a musical sound results, the height or acuteness of which increases with the number of the impulses communicated to the ear within a given time. A sound of definite musical value is also produced when each of the impulses, succeeding each other thus at regular intervals, is itself compounded of several undulations, in such a way that it would alone give the impression of an unmusical sound; that is to say, by a sufficiently rapid succession of short unmusical sounds, at regular intervals, a musical sound is generated.

It would appear that two impulses, which are equivalent to four single or half vibrations, are sufficient to produce a definite note, audible as such, through the auditory nerve. The note produced by the shocks of the teeth of a revolving wheel, at regular intervals upon a solid body, is still heard when the teeth of the wheel are removed in succession until two only are left; the sound produced by the impulses of these two teeth has still the same definite value in the scale of music.

The maximum and minimum of the intervals of successive impulses still appreciable through the auditory nerve as determinate sounds, have been determined by M. Savart. If their intensity is sufficiently great, sounds are still audible which result from the succession of 48,000 half vibrations, or 24,000 impulses in a second; and this, probably, is not the extreme limit in acuteness of sounds perceptible by the ear. For the opposite extreme, he has succeeded in rendering sounds audible which were produced by only fourteen or eighteen half vibrations, or seven or eight impulses, in a second; and sounds still deeper might probably be heard, if the individual impulses could be sufficiently prolonged.

By removing one or several teeth from the toothed wheel before mentioned, M. Savart was also enabled to satisfy himself of the

repeated for a long time, then the sensation produced may continue for a very long time, more than twelve or twenty-four hours even, after the original cause of the sound has ceased. This must have been experienced by every one who has travelled several days continuously; for some time after the journey the rattling noises are heard when the ear is not acted on by other sounds.

We have here a proof that the perception of sound as sound, is not essentially connected with the existence of undulatory pulses; and that the sensation of sound is a state of the auditory nerve, which, though it may be excited by a succession of impulses, may also be produced by other causes. The sensations of the retina remaining after the external impression of light has ceased, have been attributed to a retention of some of the matter of light for a certain time by the retina, as in the absorption of light by dark bodies; but in the case of the sense of hearing, such an hypothesis is evidently untenable. No irritating matter and no impulse can be here retained; and, even if it be supposed that undulations excited by the impulse are kept up in the auditory nerve for a certain time, they must be undulations of the nervous principle itself, which, being excited, continue until the equilibrium is restored.

Corresponding to the double vision of the same object with the two eyes, is the double hearing with the two ears; and analogous to the double vision with one eye, dependent on unequal refraction, is the double hearing of a single sound with one ear, owing to the sound coming to the ear through media of unequal conducting power. The first kind of double hearing is very rare; instances of it are recorded, however, by Sauvages and Itard. The second kind, which depends on the unequal conducting power of two media through which the same sound is transmitted to the ear, may easily be experienced. If a small bell be sounded in water, while the ears are closed by plugs, and a solid conductor is interposed between the water and the ear, two sounds will be heard, differing in intensity and tone; one being conveyed to the ear through the medium of the atmosphere, the other through the conducting-rod.

The sense of vision may vary in its degree of perfection as regards either the faculty of adjustment to different distances, the power of distinguishing accurately the particles of the retina affected, sensibility to light and darkness, or the perception of the different shades of colors. In the sense of hearing, there is no parallel to the faculty by which the eye is accommodated to distance, nor to the perception of the particular part of the nerve affected; but just as one person sees distinctly only in a bright light, and another only in a moderate light, so in different individuals

are unknown.

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dominal viscera, and in febrile affections. Here, also, it is probable that the central organs of the nervous system are the media through which the impression is transmitted.

SENSE OF TASTE.

The conditions for the perception of taste are: 1, the presence of a nerve with special endowments; 2, the irritation of this nerve by the sapid matters; 3, the solution of these matters in the secretions of the organ of taste. The nerves concerned in the production of the sense of taste have been already considered (p. 356).

The mode of action of the substances which excite taste probably consists in the production of a change in the internal condition of the gustatory nerves, and, according to the difference of the substances, an infinite variety of changes of condition, and consequently of tastes, may be induced. It is not, however, necessary for the manifestation of taste that sapid substances in solution should be brought into contact with its nerves. For the nerves of taste, like the nerves of other special senses, may have their peculiar properties excited by various other kinds of irritation, such as electricity and mechanical impressions. Thus Henle observed that a small current of air directed upon the tongue gives rise to a cool saline taste, like that of saltpetre; and Dr. Baly has shown that a distinct sensation of taste, similar to that caused by electricity, may be produced by a smart tap applied to the papillæ of the tongue. Moreover, the mechanical irritation of the fauces and palate produces the sensation of nausea, which is probably only a modification of taste.

The matters to be tasted must either be in solution or be soluble in the moisture covering the tongue; hence insoluble substances are usually tasteless, and produce merely sensations of touch. Moreover, for a perfect action of a sapid, as of an odorous substance, it is necessary that the sentient surface should be moist. Hence when the tongue and fauces are dry, sapid substances, even in solution, are with difficulty tasted.

The principal, but not exclusive, seat of the sense of taste is the fauces and tongue. The tongue is a muscular organ, whose use in relation to mastication and deglutition has already been considered (p. 163). The free surface is covered with structures analogous to those of the skin, namely, a *cutis* or *corium*, on which are placed *papillæ*, and which, together with them, is invested by *epithelium*.

The cutis is thinner and less dense than that of the skin, but is

Tongue, seen on its upper surface: *a*. One of the circumvallate papillæ. *b*. One of the fungiform papillæ. Numbers of the conical papillæ are seen about *d*, and elsewhere. *c*. Glottis, epiglottis, and glosso-epiglottidean folds of mucous membrane.—From Semmering.

outside of which again is a slightly

The *epithelium* of the tongue is of the tessellated kind, like that of the epidermis (p. 245). It covers every part of the surface, but over the fungiform papillæ forms a thinner layer than elsewhere, so that these papillæ stand out more prominently than the rest. The epithelium covering the conical papillæ has been shown by Todd and Bowman (xxxix. 382, Am. Ed.), to have a singular arrangement; being extremely dense and thick, and projecting from their sides and summits in the form of long, stiff, hair-like processes. Many of these processes bear a close resemblance in structure to hairs, and some actually contain minute hair-tubes.

Each of the three varieties of papillæ just described have been commonly regarded as simple processes, like the papillæ of the skin, but Todd and Bowman have shown that the surface of each is studded by minute conical processes of mucous membrane, which thus form secondary papillæ. These secondary papillæ also occur over most other parts of the tongue, not occupied by the compound papillæ. They are commonly buried beneath the epithelium; hence have been hitherto overlooked.

Such, in outline, is the structure of the sensitive surface of the tongue. But the tongue is not the only seat of the sense of taste, for the results of experiments as well as ordinary experience show that the soft palate and its arches, the uvula, tonsils, and probably the upper part of the pharynx are endowed with taste. These parts, together with the base and posterior part of the tongue, are supplied with branches of the glosso-pharyngeal nerve, and evidence has been already adduced (p. 357) that the sense of taste is conferred upon them by this nerve.

In most, though not in all, persons the anterior part of the tongue, especially the edges and tip, are supplied with taste. The middle of the dorsum is only feebly endowed with this sense, probably because of the destiny and thickness of the epithelium covering the filiform papillæ of this part of the tongue, which will prevent the sapid substances from penetrating to their sensitive parts. The use of these papillæ is, therefore, probably less for taste than for mechanical purposes in the act of mastication. The gustatory property of the anterior part of the tongue is due, as already said (pp. 350, 357) to the lingual branches of the fifth nerves.

Besides the sense of taste, the tongue, by means also of its papillæ, is endued, especially at its sides and tip, with a very delicate and accurate sense of touch, which renders it sensible of the impressions of heat and cold, pain, and mechanical pressure, and consequently of the form of surfaces. The tongue may lose its common sensibility, and still retain the sense of taste, and *vice versâ*. This fact renders it probable that although the senses of taste and of touch may be exercised by the same papillæ, supplied by the same nerves, yet the nervous conductors for these two different

...a common sensation and

The concurrence of common part makes it sometimes difficu... son produced by a substance ... two tongues, or through those of ... indeed, it is probable that both ... as when irritating acrid substan...

The impressions on the mind ... seem to result, as already said, fr... condition of the nerves pervaded ... with the papillæ in which the fib... This explanation, obscure though ... the sense: but the variations of ... stances are as yet inexplicable. ... that sounds differ from one anothe... the number of undulations produ... vision it is reasonably inferred ... differences in the number of undu... of the imponderable principle of ... and smell, no such probable explan... would appear, indeed, from the ... that while some substances taste a... surface, others excite different tast... to different papillæ of the tongue. ... would seem to show that, in some ... capable of receiving different impr... stance.

M...

other substances applied to the tongue afterwards. Thus, of sweet substances spoils the flavor of wine, the taste of mproves it. There appears, therefore, to exist the same between tastes as between colors, of which those that are or complementary, render each other more vivid, though al principles governing this relation have been discovered ase of tastes. In the art of cooking, however, attention l times been paid to the consonance or harmony of flavors combination or order of succession, just as in painting and ıe fundamental principles of harmony have been employed lly while the theoretical laws were unknown.

ent and continued repetition of the same taste renders the n of it less and less distinct, in the same way that a color more and more dull and indistinct, the longer the eye is on it. Thus, after frequently tasting first one and then the two kinds of wine, it becomes impossible to discriminate them.

imple contact of a sapid substance with the surface of the y organ seldom gives rise to a distinct sensation of taste; to be diffused over the surface, and brought into intimate vith the sensitive parts by compression, friction, and motion the tongue and palate.

ense of taste seems capable of being excited also by in- ıuses, such as changes in the conditions of the nerves or centres, produced by congestion or other causes which ex- ective sensations in the other organs of sense. But, little ı of the subjective sensations of taste; for it is difficult to sh the phenomena from the effects of external causes, such es in the nature of the secretions of the mouth.

SENSE OF TOUCH.

ense of touch is not confined to particular parts of the small extent, like the other senses; on the contrary, all ıable of perceiving the presence of a stimulus by ordinary ı are, in various degrees, the seat of this sense; for touch r a modification or exaltation of common sensation or sen- The nerves on which the sense of touch depends are, , the same as those which confer ordinary sensation on the parts of the body, viz., the posterior ganglionic roots of es of the spinal cord, and the sensitive cerebral nerves.

lthough all parts of the body supplied with sensitive nerves , in some degree, organs of touch, yet the sense is exercised tion in only those parts the sensibility of which is extremely *e. g.*, the skin, the tongue and the lips, which are provided ndant papillæ.

... position. But, from the abu
fibres which it receives, it is enal
purpose in serving as the princi
The entire surface of the skin is
properties are due chiefly to the a
studded. These papillæ have al
elevations of the corion, more pro
some parts than at others (p. 257)
most abundant and most prominen
hands and fingers, and the soles
which the sense of touch is most a
skin they are more or less thinly sca

Fig. 113.

Fig. 113. Papillæ of the palm, the cuticle being
Fig. 114. Vessels of papillæ, from the heel: *a*,
vein. Magnified 80 diameters.

above the surf

The mode in which this fibre terminates, whether by a loop or by a free extremity, or, after parting with its external white substance, by being lost in the tissue of the papillæ, has still to be ascertained. The bloodvessels and terminal nerve-fibres are distributed, in a kind of fibrous structure, which gives to the papillæ its form and a certain degree of firmness.

Although destined especially for the sense of touch, the papillæ are not so placed as to come into direct contact with external objects, but, like the rest of the surface of the skin, are covered by one or more layers of epithelium, forming the cuticle or epidermis (p. 260). The papillæ adhere very intimately to the cuticle, which is thickest in the spaces between them, but tolerably level on its outer surface: hence, when stripped off from the cutis, as after maceration, its internal surface presents a series of pits and elevations corresponding to the papillæ and their interspaces, of which it thus forms a kind of mould. Besides affording by its impermeability a check to undue evaporation from the skin, and providing the sensitive cutis with a protecting investment, the cuticle is of service in relation to the sense of touch. For, by being thickest in the spaces between the papillæ, and only thinly spread over the summits of these processes, it may serve to subdivide the percipient surface of the skin into a number of isolated points, each of which is capable of receiving a distinct impression from an external body. By covering the papillæ, it renders the sensation produced by external bodies more obtuse, and in this manner also is subservient to touch: for unless the very sensitive papillæ were thus defended, the contact of substances would give rise to pain, instead of the ordinary impressions of touch. This is shown in the extreme sensitiveness and loss of tactile power in a part of the skin when deprived of its epidermis. If the cuticle is very thick, however, as on the heel, touch becomes imperfect, or is lost, through the inability of the tactile papillæ to receive impressions through the dense and horny layer covering them.

The sensations of the common sensitive nerves have as peculiar a character as those of any other organ of sense. The sense of touch renders us conscious of the presence of a stimulus, from the slightest to the most intense degree of its action, neither by sound, nor by light, nor by color, but by that indescribable something which we call feeling, or common sensation. The modifications of this sense often depend on the extent of the parts affected. The sensation of pricking, for example, informs us that the sensitive particles are intensely affected in a small extent; the sensation of pressure indicates a slighter affection of the parts in a greater extent, and to a greater depth. It is by the depth to which the parts are affected, that the feeling of pressure is distinguished from that of mere contact.

By the sense of touch, the mind is made acquainted with the size, form, and other external characters of bodies. And in order that these characters may be easily ascertained, the sense of touch is especially developed on those parts which can be readily moved over the surface of bodies. Touch, in its more limited sense, or the act of examining a body by the touch, consists merely in a voluntary employment of this sense combined with movement, and stands in the same relation to [illegible] or common sensibility, generally, as the act of [illegible] or examining odors, does to the sense of smell. [illegible] part of the body which can, by means of movement, [illegible] different relations of contact with external bodies [illegible] of "touch." No one part, consequently, has exclusive [illegible] tion. The hand, however, is best adapted for [illegible] peculiarities of structure—namely, the capability [illegible] of supination, which enables it, by the movement [illegible] amine the whole circumference of a body; the power of opposing the thumb to the rest of the [illegible] the mobility of the fingers.

In estimating the extent of a surface, the mind [illegible] the size of the hand or fingers used in the inquiry [illegible] from which it is combined in the surface tra[illegible], and [illegible] comparing this process with regard to the different [illegible] of the body acquires a notion of its cubical extent.

The [illegible] of the sense of touch in different parts of the surface is [illegible] to the power which such parts possess of distinguishing and [illegible] the sensation produced by two points [illegible] together. This power depends, at least in part, on the number of [illegible] distributed to the part; for the more numerous these nerves are which an organ receives, the more likely is it that [illegible] impressed on different contiguous points will [illegible] as such, as they will hence be confounded, and perceived only [illegible] sensation. Experiments to determine the [illegible] of different parts of the skin, as measured by this power of distinguishing distances, were made by E. H. Weber. The experiments consisted in touching the skin, while the eyes were closed, with the points of a pair of compasses sheathed with cork, and in ascertaining how near the points of the compasses might be brought to each other and still be felt as two bodies. He examined in this manner nearly every part of the surface of the body, and has given tables showing the relative degrees of sensibility of different parts. Experiments of a similar kind have been performed also by Valentin (v. l. ii. p. 566); and, among the numerous results obtained by both these investigators, it appears that the extremity of the third finger and the point of the tongue are the parts most sensitive; a distance of as little as half a line being here distinguished. Next in sensitiveness to these is the mucous surface of

the lips, which can perceive the two points of the compass when separated to the distance of about a line and a half: on the dorsum of the tongue they require to be separated two lines. The parts in which the sense of touch is least acute are the neck, the middle of the back, the middle of the arm, and the middle of the thigh, on which the points of the compass have to be separated to the distance of thirty lines to be perceived as distinct points (Weber). Other parts of the body possess various degrees of sensibility intermediate between the above extremes. (For Weber's table, see xxxii. p. 546, Am. Ed.; for Valentin's, iv. vol. ii. p. 566.)

A sensation in a part endowed with touch appears to the mind to be, *cæteris paribus*, more intense when it is excited in a large extent of surface than when it is confined to a small space. The temperature of water, into which he dipped his whole hand, appeared to Weber to be higher than that of water of really higher temperature, in which he immersed only one finger of the other hand. Similar observations may be made by persons bathing in warm or cold water.

Part of the ideas which we obtain of the conditions of external bodies is derived through the peculiar sensibility with which muscles are endowed—the sensibility by which we are made acquainted with their position, and the degree of their contraction. By this sensation we are enabled to estimate the degree of force exerted in resisting pressure or in raising weights. The estimate of weight by muscular effort is more accurate than that by pressure on the skin, according to Weber, who states that by the former a difference between two weights may be detected when one is only one-twentieth or one-fifteenth less than the other. It is not the absolute, but the relative, amount of the difference of weight which we have thus the faculty of perceiving.

It is not, however, certain that our idea of the amount of muscular force used is derived solely from sensation in the muscles. We have the power of estimating very accurately beforehand, and of regulating, the amount of nervous influence necessary for the production of a certain degree of movement. When we raise a vessel, with the contents of which we are not acquainted, the force we employ is determined by the idea we have conceived of its weight. If it should happen to contain some very heavy substance, as quicksilver, we shall probably let it fall; the amount of muscular action, or of nervous energy, which we had exerted, being insufficient. The same thing occurs sometimes to a person descending stairs in the dark; he makes the movement for the descent of a step which does not exist. It is possible that in the same way the idea of weight and pressure in raising bodies or in resisting forces, may in part arise from a consciousness of the amount of nervous energy transmitted from the brain, rather than from a sensation in

the muscles themselves. The mental conviction of the inability longer to support a weight must also be distinguished from the actual sensation of fatigue in the muscles.

So, with regard to the ideas derived from sensations of touch combined with movements, it is doubtful how far the consciousness of the extent of muscular movement is obtained from sensations in the muscles themselves. The sensation of movement attending the motions of the hand is [illegible] nd persons who do not know that the action of parti[illegible] necessary for the production of given movements, d[illegible] the movement of the fingers, for example, depends [illegible] he forearm. The mind has, nevertheless, a very de[illegible] e of the changes of position produced by movement [illegible] this that the ideas which it conceives of the exten[illegible] a body are in great measure founded.

In order that an impression made on a sensitive surface may be perceived, it is necessary that there should exist a reciprocal influence between the mind and the sense of touch; for, if the mind does not thus co-operate, the organic conditions for the sensation may be fulfilled, but it remains unperceived. Moreover, the distinctness and intensity of a sensation in the nerves of touch depend in great measure on the degree in which the mind co-operates for its perception. A painful sensation becomes more intolerable the more the attention is directed to it; thus, a sensation in itself inconsiderable, as an itching in a very small spot of the skin, may be rendered very troublesome and enduring.

As every sensation is attended with an idea, and leaves behind it an idea in the mind which can be reproduced at will, we are enabled to compare the idea of a past sensation with another sensation really present. Thus we can compare the weight of one body with another which we have previously felt, of which the idea is retained in our mind. Weber was, indeed, able to distinguish in this manner between temperatures experienced one after the other better than between temperatures to which the two hands were simultaneously subjected. This power of comparing present with past sensations diminishes, however, in proportion to the time which has elapsed between them.

The *after-sensations* left by impressions on nerves of common sensibility or touch are very vivid and durable. As long as the condition into which the stimulus has thrown the organ endures, the sensation also remains, though the exciting cause should have long ceased to act. Both painful and pleasurable sensations afford many examples of this fact.

The law of *contrast*, which we have shown to modify the sensations of vision (p. 432), prevails here also. After the body has

been exposed to a warm atmosphere, a degree of temperature very little lower, which would under other circumstances be warm, produces the sensation of cold; and a sudden change to the extent of a few degrees from a cold temperature to a warm one, will produce the sensation of warmth. Heat and cold are, therefore, relative terms; for a particular state of the sentient organ causes what would otherwise be warmth to appear cold. So, also, a diminution in the intensity of a long-continued pain gives pleasure, even though the degree of pain that remains would in the healthy state have seemed intolerable.

Subjective sensations, or sensations dependent on internal causes, are in no sense more frequent than in the sense of touch. All the sensations of pleasure and pain, of heat and cold, of lightness and weight, of fatigue, &c., may be produced by internal causes. Neuralgic pains, the sensation of rigor, formication, or the creeping of ants, and the states of the sexual organs occurring during sleep, afford striking examples of subjective sensations.

The mind, also, has a remarkable power of exciting sensations in the nerves of common sensibility; just as the thought of the nauseous excites sometimes the sensation of nausea, so the idea of pain gives rise to the actual sensation of pain in a part predisposed to it. The thought of anything horrid excites the sensation of shuddering; the feelings of eager expectation, of pathetic emotion, of enthusiasm, excite in some persons a sensation of "concentration" at the top of the head, and of cold trickling through the body; fright causes sensations to be felt in many parts of the body; and even the thought of tickling excites that sensation in individuals very susceptible of it, when they are threatened with it by the movements of another person. These sensations from internal causes are most frequent in persons of excitable nervous systems, such as the hypochondriacal and the hysterical, of whom it is usual to say that their pains are imaginary. If by this is meant that their pains exist in their imagination merely, it is certainly quite incorrect. Pain is never imaginary in this sense; but is as truly pain when arising from internal as from external causes; the idea of pain only can be unattended with sensation, but of the mere idea no one will complain. Still, it is quite certain that the imagination can render pain that already exists more intense, and can excite it when there is a disposition to it.

CHAPTER XIX.

GENERATION AND DEVELOPMENT.

THE several organs of the human body, which have been considered in the preceding chapters, have relation to the individual being. We shall now consider those organs and functions which are made for the propagation of the species. These comprise the formation, impregnation, and development of the ovum, from which the embryo or fœtus is produced, and which is perfected into a living human being.

The organs concerned in effecting these objects, are named the generative organs, or sexual apparatus, since part belong to the male and part to the female sex.

Generative Organs of the Female.

The female organs of generation consist of two *Ovaries*, for the formation of ova; of a *Fallopian tube*, or oviduct, connected with each ovary, for the purpose of conducting the mature ovum to the *uterus*, or cavity, in which, if impregnated, it is retained until the embryo is fully developed, and fitted to maintain its existence, independent of internal connection with the parent; and, lastly, of a passage, or *vagina*, with its appendages, for the reception of the male generative organ in the act of copulation.

The *ovaries* are two oval compressed bodies, situated in the cavity of the pelvis, one on each side, inclosed in the folds of the broad ligament. Each ovary is attached to the uterus by a narrow fibrous cord (the ligament of the ovary), and, more slightly, to the Fallopian tube, by one of the fimbriæ into which the walls of the extremity of the tube expand. The ovary is enveloped by a *capsule* of dense fibro-cellular tissue, which again is surrounded by peritoneum. The internal structure of the organ consists of a peculiar soft fibrous tissue, or *stroma*, abundantly supplied with bloodvessels, and having imbedded in it, in various stages of development, numerous minute follicles, or vesicles, the *Graafian vesicles*, or sacculi, containing the ova. A further account of the Graafian vesicles, and of their contained ova, will be presently given.

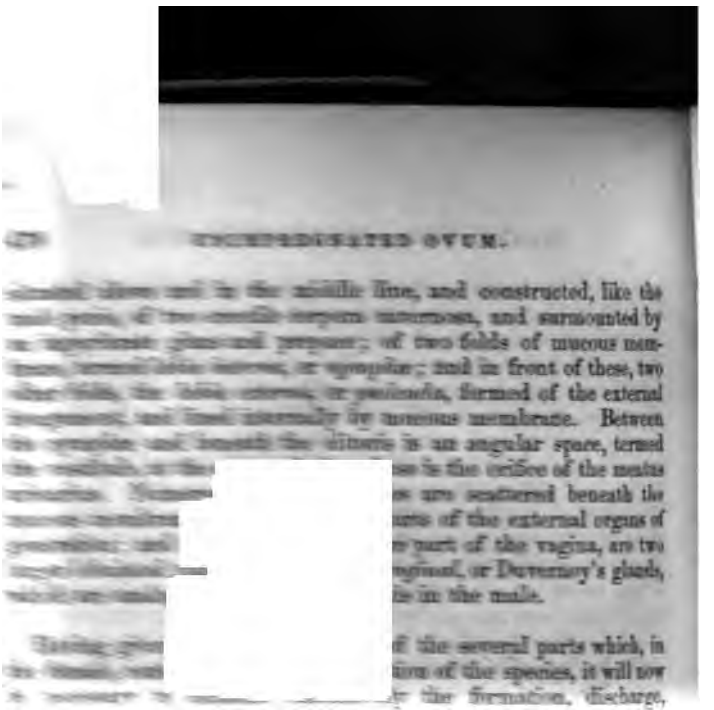
The *Fallopian tubes* are about four inches in length, and extend between the ovaries and the upper angles of the uterus. At the point of attachment to the uterus, the Fallopian tube is very nar-

row, but in its course to the ovary, it increases to about a line and a half in thickness; at its distal extremity, which is free and floating, it bears a number of *fimbriæ*, one of which, longer than the rest, is attached to the ovary. The canal by which each Fallopian tube is traversed, is narrow, especially at its point of entrance into the uterus, at which, it will scarcely admit a bristle; its other extremity is wider, and opens into the cavity of the abdomen, surrounded by the zone of fimbriæ. Externally, the Fallopian tube is invested with peritoneum; internally, its canal is lined with mucous membrane, covered with ciliary epithelium (p. 374): between the peritoneal and mucous coats the walls are composed of fibrous tissue, similar to that of the uterus.

The *uterus* is a somewhat pyriform, fibrous organ, with a central cavity lined with mucous membrane. In the unimpregnated state it is about three inches in length, two in breadth at its upper part, or *fundus*, but at its lower pointed part, or *neck*, only about half an inch. The part between the fundus and neck is termed the body of the uterus: it is about an inch in thickness. The walls of the organ are composed of dense fibro-cellular tissue, which, in the impregnated state, are developed into fibres of organic muscle. The cavity of the uterus corresponds in form to that of the organ itself: it is very small in the unimpregnated state; the sides of its mucous surfaces being almost in contact, and probably only separated from each other by mucus. Into its upper part, at each side, opens the canal of the corresponding Fallopian tube: below, it communicates with the vagina by a fissure-like opening in its neck, the *os uteri*, the margins of which are distinguished into two lips, an anterior and posterior. At the mucous membrane of the cervix are found several mucous follicles, termed Ovula, or glandulæ Nabothi: they probably form the jelly-like substance by which the os uteri is usually found closed.[1]

The *vagina* is a membranous canal, six or eight inches long, extending obliquely downwards and forwards from the neck of the uterus, which it embraces, to the external organs of generation. It is lined with mucous membrane, which in the ordinary contracted state of the canal is thrown into transverse folds. External to the mucous membrane the walls of the vagina are constructed of fibro-cellular tissue, within which, especially around the lower part of the tube, is a layer of erectile tissue. The anterior extremity of the vagina is embraced by an orbicular muscle, the constrictor vaginæ; its external orifice is, in the virgin, partially closed by a fold or ring of mucous membrane, termed the *hymen*. The external organs of generation consist of the *clitoris*, a small elongated body,

[1] For an account of the arrangement of the fibres of the uterus, see xxxvi. Jan. 1845.



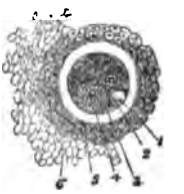
albuminous fluid in which microscopic granules float; and ains also the *ovum* or *ovule*. The ovum is a minute spheri- y situated, in immature follicles, near their centre; but in earer maturity, in contact with the membrana granulosa, at rt of the follicle which forms a prominence on the surface ovary. The cells of the membrana granulosa are at that nore numerous than elsewhere, and are heaped around the forming a kind of granular zone, the *discus proligerus* (Fig.

rder to examine an ovum, one of the Graafian vesicles, it s not whether it be of small size or arrived at maturity, be pricked and the contained fluid received upon a piece of The ovum then, being found in the midst of the fluid by of a simple lens, may be further examined with higher opic powers. Owing to its globular form, however, its re cannot be seen until it is subjected to gentle pressure.

human ovum is extremely small, measuring, according to ff, from 1-240th to 1-120th of an inch. Its external in- nt is a transparent membrane, about 1-2500th of an inch kness, which, under the microscope, appears as a bright ig. 116), bounded externally and internally by a dark out- t is called the *zona pellucida*, or *vitelline membrane*, and onds with the *chorion* of the impregnated ovum. It s externally to the heap of cells constituting the discus rus.

hin this transparent investment, or zona pellucida, and in close contact with it, lies the *yelk*, or *vitellus*, which is ed of granules and globules of various sizes, imbedded in a r less fluid substance. The smaller s, which are the more numerous, re- in their appearance, as well as their t motion, pigment granules. The granules or globules which have the of fat globules, are in greatest number periphery of the yelk. The number granules is, according to Bischoff, t in the ova of carnivorous animals. human ovum their quantity is com- ely small.

Fig. 116.



Ovum of the sow, after Barry. 1. Germinal spot. 2. Germinal vesicle. 3. Yelk. 4. Zona pellucida. 5. Discus proligerus. 6. Adherent granules, or cells.

substance that combines the globules nules of the yelk is, in many animals, luid. The yelk then completely fills ity of the zona pellucida, and escapes iquid form when the membrane is d: but in ova of the human subject ne animals the yelk is much more consistent, and sometimes

escapes as a solid globular mass when the zona pellucida is torn. It is, according to Bischoff, solely owing to this firm consistence of the yelk, that it in many cases preserves its form, when a watery fluid passes by imbibition through the zona pellucida, and that an interval is then apparent between the yelk and that membrane. From the appearances resulting from the action of water on the ovum, and from other circumstances, it has been thought that the mass composing the [illegible] ided by another membrane within the zona pellu[illegible] idence for such a view is not satisfactory (see clxx

In the substance [illegible] edded the *germinal vesicle*, or vesicula germina[illegible]). This vesicle is of greatest relative size in the [illegible] in them surrounded closely by the yelk, nearly [illegible] which it lies. During the development of th[illegible] al vesicle increases in size much less rapidly [illegible] comes to be placed near to it surface. In a [illegible] abbit, it is about one-sixtieth of a line in diameter (Bischoff); its size in the human ovum has

Fig. 117.

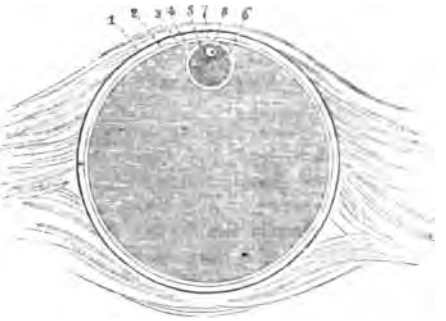


Diagram of a Graafian vesicle, containing an ovum: 1. Stroma or tissue of the ovary. 2 and 3. External and internal tunics of the Graafian vesicle. 4. Cavity of the vesicle. 5. Thick tunic of the ovum, or yelk-sac. 6. The yelk. 7. The germinal vesicle. 8. The germinal spot.

not yet been ascertained, owing to the difficulty of isolating it. It consists of a fine, transparent, structureless membrane, containing a clear watery fluid, in which are sometimes a few granules.

At that part of the periphery of the germinal vesicle which is nearest to the periphery of the yelk is situated the *germinal spot*, a finely-granulated substance, of a yellowish color, strongly refracting the rays of light, and measuring, in the Mammalia generally, from 1-3600th to 1-2400th of an inch (Wagner).

Such are the parts of which the Graafian follicle and its contents, ıcluding the ovum, are composed. The diagram (Fig. 117) repre-ıts them in their relative positions when mature.

It remains still to say something of the mode of development of, ıd subsequent changes in, these several parts; especially in rela-on to the questions whether the Graafian vesicle is the immediate rmative organ of the ovum; in what order the several parts of ıe ovum are formed; and the changes which they undergo in the rogress of the ovum to maturity.

The first question may be answered in the affirmative, for the esearches of Valentin and Bischoff have shown that the Graafian esicle is formed previous to the ovum, which is subsequently deve-ped in it. Bischoff and Barry agree that the development of the raafian vesicles and ova continues uninterruptedly from birth to he end of the fruitful period of woman's life. In some animals, s the cow and sow, it commences in the embryo, even at an early eriod of uterine existence, but in the dog and rabbit not till after irth. Bischoff describes the process of formation of the Graafian esicles and ova to be as follows: At first, nothing can be dis-inguished in the substance of the ovary but primary cells and uclei of cells; then round groups of similar cells are seen scattered ı large numbers through the stroma. The peripheral cells of each f these groups subsequently coalesce, so as to form a homogeneous ansparent vesicular membrane, while the portion of the mass ithin becomes fluid. Thus is formed the Graafian vesicle. On ıe inner wall of this follicle, or vesicle, new cells are formed, in ıe manner of an epithelial layer, while the cavity is found to con-ain a transparent fluid, with nuclei of cells and granules, exactly esembling yelk-granules, suspended in it. The next stage is marked y the appearance of a second smaller transparent vesicle within ıe Graafian vesicle. This second vesicle, which is the germinal esicle, has a nucleus, the germinal spot. Granules, similar to elk-granules, soon accumulate around the germinal vesicle; but ıe further steps in the development of the ovum could not be raced. All its parts were completely formed when Bischoff next bserved it. A somewhat different account is given by Valentin xxx. 1838), of the mode in which the Graafian vesicle is deve-ped, but he agrees with Bischoff that it is formed previous to the vum.

With regard to the parts of the ovum first formed, it appears ertain that the formation of the germinal vesicle precedes that of ıe yelk and zona pellucida, or vitelline membrane. Whether the erminal spot is formed first, and the germinal vesicle afterwards eveloped around it, cannot be decided in the case of vertebrate ıimals; but some recent observations of Kölliker and Bagge, on ıe development of the ova of intestinal worms, shew that in these

earlier the stage of developmen
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Graafian vesicle. For, as the
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contents of the vesicle between it
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According to Bischoff, the num
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probably never attain full development, but soon shrivel and disappear instead of bursting as matured follicles do; the contained ova are also incapable of being impregnated. But coincident with the other changes which occur in the body at the time of puberty, the ovaries enlarge, and become very vascular, the formation of Graafian vesicles is more abundant, the size and degree of development attained by them are greater, and the ova are capable of being fecundated.

Discharge of the Ovum.

In the process of development of individual vesicles, it has been already observed that as each increases in size it gradually approaches the surface of the ovary, and, when fully ripe or mature, forms a little projection on the exterior. Coincident with the increase in size caused by the augmentation of its liquid contents, the external envelop of the distended vesicle becomes very thin and eventually bursts. By this means the ovum and fluid contents of the Graafian vesicle are liberated and escape on the exterior of the ovary, whence they pass into the Fallopian tube, the fimbriated processes of the extremity of which are supposed coincidently to grasp the ovary, while the aperture of the tube is applied to the part corresponding to the matured and bursting vesicle.

In animals whose capability of being impregnated occurs at regular periods, as in the human subject, and most Mammalia, the Graafian vesicles and their contained ova appear to arrive at maturity, and the latter to be discharged, at such periods only. But in other animals, *e. g.*, the common fowl, the formation, maturation, and discharge of ova appear to take place almost constantly.

It has long been known that in the so-called oviparous animals the separation of ova from the ovary may take place independently of impregnation by the male, or even of sexual union. And it is now established, especially by the labors of Bischoff (clxxvii.), Raciborski (clxxviii.), and Pouchet (clxxix.), that a like maturation and discharge of ova, independently of coition, occurs in Mammalia, and most probably also in the human subject: the periods at which the matured ova are separated from the ovaries and received into the Fallopian tubes being indicated, in Mammalia, by the phenomena of *heat*, or *rut;* in the human female, by the phenomena of *menstruation*. Sexual desire manifests itself in the human female with greater intensity at these periods, and in the females of mammiferous animals at no other time. If the union of the sexes takes place, the ovum may be fecundated, but if no union occurs it perishes.

In proof that the phenomena of heat in mammiferous animals are coincident with the discharge of ova from the ovaries, independent of the influence of the male, abundant evidence has been collected. Thus Blundell (xli. vol. x.), Hausmann (clxxv.), and

Many circumstances make it probable that the human female is subject, in these respects, to the same law as the females of other mammiferous animals; namely, that in her, as in them, ova are matured and discharged from the ovary independent of sexual union, and that this maturation and discharge occur periodically at the epochs of menstruation. Thus Graafian vesicles recently ruptured have been frequently seen in the ovaries of virgins or women who could not have been recently impregnated; and although it is true that the ova discharged under these circumstances have not hitherto been discovered in the Fallopian tube, partly on account of their minute size, and partly because the search has seldom been prosecuted with much care; yet analogy forbids us to doubt that in the human female, as in the domestic quadrupeds, the result and purpose of the rupture of the follicles is the discharge of the ova.

The evidence of the periodical discharge of ova at the epochs of menstruation is first, that nearly all authors who have touched on the point, agree that no traces of follicles having burst are ever seen in the ovaries before puberty or the first menstruation; secondly, that in all cases in which ovarian follicles have been found burst independently of sexual intercourse, the women were at the time menstruating, or had very recently passed through the menstrual state; thirdly, that although in women sexual connection is not confined to the periods of menstruation, yet conception is more likely to occur within a few days after the cessation of the menstrual flux than at other times; and, lastly, that the ovaries of the human female become turgid and vascular at the menstrual periods as those of animals do at the time of heat.

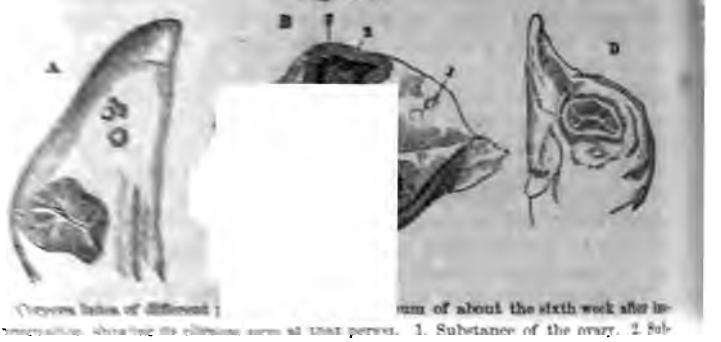
From what has been said, it may therefore be concluded that the two states heat and menstruation are analogous, and that the essential accompaniment of both is the maturation and extrusion of ova. In both there is a state of active congestion of the sexual organs, sympathizing with the ovaries at the time of the highest degree of development of the Graafian vesicles; and in both the crisis of this state of congestion is attended by a discharge of blood, or mucus, or both, from the external organs of generation.

The occurrence of a menstrual discharge is one of the most prominent indications of the commencement of puberty in the female sex; though its absence even for several years is not necessarily attended with arrest of the other characters of this period of life, or with inaptness for sexual union, or incapability of impregnation. The average time of its first appearance, in females of this country, and others of about the same latitude, is from fourteen to fifteen; but is much influenced by the kind of life to which girls are subject; being accelerated by habits of luxury and indolence, and retarded by contrary conditions. On the whole, its appearance is earlier in persons dwelling in warm climates than in

ı to be separated by the thinnest possible lamina of semi-
arent tissue.
ıen a Graafian vesicle is about to burst and expel the ovum,
›mes highly vascular and opaque; and, immediately before
pture takes place, its walls appear thickened on their inte-
y a reddish glutinous or fleshy-looking substance. Imme-
y after the rupture, the inner layer of the wall of the vesicle
rs pulpy and flocculent. It is thrown into wrinkles by the
ction of the outer layer, and, soon, red fleshy mamillary pro-
grow from it, and gradually enlarge till they nearly fill the
e, and even protrude from the orifice in the external covering
› ovary. Subsequently this orifice closes, but the fleshy
h within still increases during the earlier period of pregnancy,
lor of the substance gradually changing from red to yellow,
s consistence becoming firmer.
› corpus luteum of the human female (Fig. 118) differs from
f the domestic quadruped in being of a firmer texture, and
g more frequently a persistent cavity at its centre, and in the
orm cicatrix, which remains in the cases where the cavity is
rated, being proportionately of much larger bulk. The
ity of yellow substance formed is also much less: and,
ıgh the deposit increases after the vesicle has burst, yet it
ot usually form mammillary growths projecting into the cavity
› vesicle, and never protrudes from the orifice, as is the case
er Mammalia. It maintains the character of a uniform or
r uniform layer, which is thrown into wrinkles in consequence
› contraction of the external tunic of the vesicle. After
ifice of the vesicle has closed, the growth of the yellow sub-
› continues during the first half of pregnancy, till the cavity
uced to a comparatively small size, or is obliterated; in the
case, merely a white stelliform cicatrix remains in the centre
› corpus luteum.
effusion of blood generally takes place into the cavity of the
an vesicle at the time of its rupture, especially in the human
:t; but it has no share in forming the yellow body; it gradually
its coloring matter, and acquires the character of a mass of
›. The serum of the blood sometimes remains included within
ty in the centre of the coagulum, and then the decolorized
› forms a membraniform sac, lining the corpus luteum. At
times the serum is removed, and the fibrine constitutes a solid
orm mass.
› yellow substance of which the corpus luteum consists, both
e human subject and in the domestic animals, is a growth
the inner surface of the Graafian vesicle, the result of an in-
d development of the cells forming the membrana granulosa
naturally lines the internal tunic of the vesicle.

The first changes of the internal coat of the Graafian vesicle in the process of formation of a corpus luteum, seem to occur in every

Fig. 118.



(Corpora lutea of different ; um of about the sixth week after im- pregnation, showing its cellular coats at that period. 1. Substance of the ovary. 2. Sub- stance of the corpus luteum. 3. A granular coagulum in its cavity; after Dr. Patterson. C. Corpus luteum two days after delivery. 2. In the twelfth week after delivery; after Dr. Weber.)

case in which an ovum escapes; as well in the human subject as in the domestic quadrupeds. If the ovum is impregnated, the growth of the yellow substance goes on during nearly the whole period of gestation, and forms the large corpus luteum commonly described as a characteristic mark of impregnation. If the ovum is not impregnated, the growth of yellow substance on the internal surface of the vesicle proceeds, in the human ovary, no further than the formation of a thin layer, which shortly disappears; but in the lower animals it continues for some time after the ovum has perished, and forms a corpus luteum of considerable size. The fact that a structure, in its essential characters similar to, though smaller than, a corpus luteum, observed during pregnancy, is formed in the human subject independent of impregnation or of sexual union, coupled with the varieties in size of corpora lutea formed during pregnancy, necessarily renders unsafe all evidence of previous impregnation founded on the existence of a corpus luteum in the ovary.[1]

IMPREGNATION OF THE OVUM.

Male Sexual Functions.

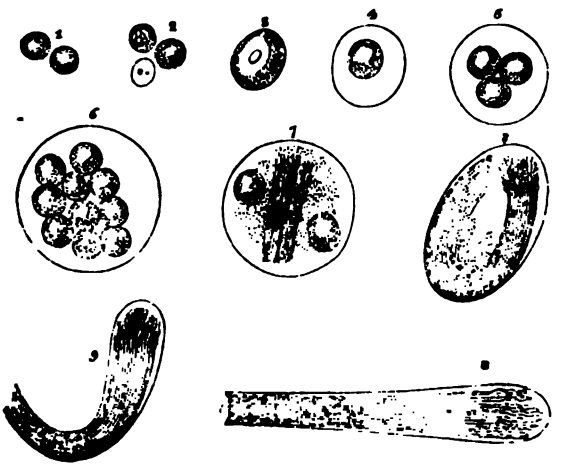
The fluid of the male, by which the ovum is impregnated, consists essentially of the semen secreted by the testicles; and to

[1] For a full discussion of all the facts relating to this question, see Dr. Baly, in the Supplement to the second edition of Müller's Physiology.

this are added, as necessary perhaps to its perfection, a material secreted by the vesiculæ seminales, in which, as in reservoirs, the semen lies before its discharge, and the secretion of the prostate gland, and of Cowper's glands. Portions of these several fluids are, probably, all discharged together with the proper secretion of the testicles.

The secreting structure of the testicle is disposed in two contiguous parts—the body of the testicle, and the epididymis, inclosed within a tough fibrous membrane, the *tunica albuginea*. The vas deferens, the main trunk of the secreting tubes, passing to the lower part of the epididymis, assumes there a much less diameter, with a very tortuous course: with its various convolutions it forms first the mass named *caput minor*, then the *body*, and then the *caput major* of the epididymis. At the last-named part the duct divides into ten or twelve small branches, the convolutions of which form coniform masses, named *coni vasculosi;* and the vessels continued from these, after anastomoses in what is

Fig. 119.



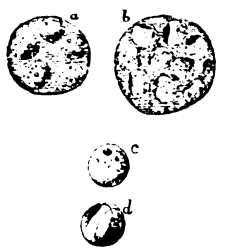
Development of the spermatozoids of Certhia familiaris (the common Creeper); after Wagner. 1. Granules of the semen, granula seminis, obtained from the testicle when very much reduced in size, during the winter; 2 to 10, different bodies found in the semen, taken from the testicle when very turgid, during the summer; 2, 3, granula seminis, of which many are probably merely cells of epithelium; 4, 5, 6, cysts, or parent cells, containing one or several round granular globules, or nuclei; 7, a similar cyst, in which are two globules, together with a mass of granules, and a fasciculus of spermatozoids in the process of development; 8, a similar cyst, become oval in form, while the spermatozoids have enlarged, and are curled up within it; 9, 10, cysts and fasciculi of spermatozoids still further developed; in 10, the fasciculus is ready to divide into separate filaments.

called the *rete testis*, lead, finally, to the tubules which form the proper substance of the testicle, wherein they are arranged in lobules, closely packed, and all attached to the tough fibrous tissue at the back of the testicle.

The tubes, *seminal tubes*, or *tubuli seminiferi*, which compose the proper substance of the testicle, are fine thread-like tubules, formed of simple homogeneous membrane, measuring on an average from 1-100th to 1-200th [illegible] and lined with epithelium or gland-cells. They ran[illegible]nd as simple tubes through a great length, with the [illegible]tructure, and probably terminate in loops. Thei[illegible]red with fine capillary blood-vessels, through whic[illegible]ir great extent in comparison with the size of the [illegible], the blood must move very slowly.

The *seminal fluid* se[illegible]esticle, is one of those secretions in which a process[illegible]t is continued after its formation by the secreting [illegible] discharge from them into the tubes. The principal part of this development consists in the formation of the peculiar bodies named *seminal filaments*, *spermatozoa*, or *spermatozoids*, the complete development of which, in their full proportion of number, is not achieved till the semen has reached, or has for some time lain in the vesiculæ seminales. Earlier, after its first secretion, the semen contains none of these bodies but granules and round corpuscles (seminal corpuscles), like large nuclei, inclosed within parent cells. Within each of these corpuscles, or nuclei, a seminal filament is developed by a similar process in nearly all animals. Each corpuscle, or nucleus, is filled with granular matter; this is gradually converted into a spermatozoid, which is at first coiled up, and in contact with the inner surface of the wall of the corpuscle (Fig. 120).

Fig. 120.



It represents the development of the spermatozoids of the rabbit: *a*. A parent cell, or cyst, with five cellules, or nuclei. *b*. A parent cell with ten cellules, each of which contains a spermatic filament. *c*. A free cellule, or nucleus, with a nucleolus and granules, more highly magnified. *d*. A cellule in which a spermatic filament is seen, the granules having disappeared.

The appearance of spermatozoids united in fasciculi, which prevails perhaps in all animals, is not owing to their mode of development, but to their tendency, when set free from their formative cellules, or nuclei, to arrange themselves thus: a tendency showing that their bodies attract each other in the same way that blood-disks do in the formation of *rouleaux*. The fasciculi are formed within the parent cell, when this remains entire after the nuclei or cellules are dissolved; in other cases

they are formed in the seminal fluid by the union of spermatozoides which have been wholly set free by the solution of both parent-cell and nuclei.

Thus developed, the human seminal filaments consist of a long, slender, tapering portion, called their body, or tail, to distinguish it from the head, an oval or pyriform portion of larger diameter, flattened, and sometimes pointed. They are from 1-500th to 1-600th of an inch in length, the length of the head alone being from 1-5000th to 1-8000th of an inch, and its width about half as much. They present no trace of structure, or dissimilar organs: a dark spot often observed in the head is, probably, due to its being concave like a blood-corpuscle. They move about in the fluid like so many minute corpuscles with each a ciliary process, lashing their tails, and propelling their heads forwards in various lines. Their movement, which is probably essentially, as well as apparently, similar to that of ciliary processes, appears nearly independent of external conditions, provided the natural density of the fluid is preserved: disturbing this condition, by either evaporating the semen or diluting it, will stop the movement. It may continue within the body of the female for seven or eight days, and out of the body for at least nearly twenty-four hours. The direction of the movement is quite uncertain; but, in general, the current that each excites keeps it from the contact of others. The rate of motion, according to Valentin, is about one inch in thirteen minutes.

Respecting the purpose served by these seminal filaments, little that is certain can be said. Their occurrence in the impregnating fluid of nearly all classes of animals proves their essentiality to the process of impregnation. They have been sometimes regarded as highly-organized, and as, in some sense or other, the materials or organs out of which the new individual is begun; by others they are considered as a kind of parasitic animalcules. But, probably, all such theories of them are erroneous. Their want of structure, and their development in cells, not by generation or succession, are inconsistent with the notion of their being, in any sense, distinct animals; neither is there evidence for believing that their entire substance is employed in the construction of the embryo. It is not safe to assume more than that they, like the blood-corpuscles, and the corpuscles of other secretions, elaborate the fluid in which they are placed, while themselves are being developed and growing; that they may therefore be regarded as a kind of floating gland-corpuscles. And, probably, they add to this function, that of assisting in the conveyance of the seminal fluid to the ovum; for they have been found, some time after the copulation of dogs and rabbits, covering the surface of the ovum in even the furthest part of the Fallopian tube; and wherever they are, they must carry

deferentia into the vesiculæ sem
emission, it may be discharged, a
with the urine which may remov
the mucus of the bladder and the
the urethra in the act of defecatio

The *vesiculæ seminales* have the
the vasa deferentia. Each of thes
prostate gland, through part of wh
urethra, gives off a side-branch, w
acute angle; and this branch dila
pursuing in both itself and its branc
the vesicula seminalis. Each of th
unravelled into a single branching
and folded up.

The mucous membrane lining the
of the gall-bladder, is minutely wri
ridges arranged so as to give it a
The rest of their walls is formed,
muscular fibres, from which they de
expulsion of their contents.

To the vesiculæ seminales a doul
for they both secrete some fluid to be
and serve as reservoirs for the semin
most constant and probably most imp
bear, guinea-pig, and several other a
seminales are large and

uid; for, in all the animals in whom they exist, and in whom the
enerative functions are exercised at only one season of the year,
e vesiculæ seminales, whether they communicate with the vasa
eferentia or not, enlarge commensurately with the testicles at the
pproach of that season.

That the vesiculæ are also reservoirs in which the seminal fluid
ay lie for a time previous to its discharge, is shown by their
mmonly containing the seminal filaments in larger abundance
an any portion of the seminal ducts themselves do. The fluid-
ke mucus, also, which is often discharged from the vesiculæ in
raining during defecation, commonly contains seminal filaments.
ut no reason can be given why this office of the vesiculæ should
ot be equally necessary to all the animals whose testicles are
ganized like those of man, or why in many animals the vesiculæ
e wholly absent.

There is an equally complete want of information respecting the
ecretions of the prostate and Cowper's glands—their nature and
urposes. That they contribute to the right composition of the
npregnating fluid, is shown both by the position of the glands,
id by their enlarging with the testicles at the approach of an ani-
al's breeding time. But that they contribute only a subordinate
rt, is shown by the fact that when the testicles are lost, though
ese other organs be perfect, all procreative power ceases.

The mingled secretions of all the organs just described form the
men, or seminal fluid. Its corpuscles are already described: its
id part has not been satisfactorily analyzed; but Henle says it
ntains fibrine, because, shortly after being discharged, flocculi
rm in it by spontaneous coagulation, and leave the rest of it thin-
r and more liquid, so that the filaments move in it more actively.

Nothing has shown what it is that makes this fluid capable of
npregnating the ovum, or (which is yet more remarkable) of
ving to the developing offspring all the characters, in features,
ze, mental disposition, and liability to disease, which belong to
e father. This is a fact wholly inexplicable; and is, perhaps,
ceeded in strangeness by none but those which show that the
minal fluid, either directly, or more probably through the me-
um of the mother, may exert such an influence, not only on the
um which it impregnates, but on many which are subsequently
npregnated by the seminal fluid of another male. It has been
ten observed, for example, that a well-bred bitch, if she have
en once impregnated by a mongrel dog, will not bear thorough-
ed puppies in the next two or three litters after that succeeding
e copulation with the mongrel. But the best instance of this
nd was in the case of a mare belonging to Lord Monson, who,
hile he was in India, and wished to obtain a cross-bred between

the horse and quagga, caused this mare to be covered by a male quagga. The foal that she next bore had distinct marks of the quagga, in the shape of its head, black bars on the legs and shoulders, and other characters. After this time she was thrice covered by horses, and every time the foal she bore had still distinct, though decreasing, marks of the quagga; the peculiar characters of the quagga being thus impressed not only on the ovum then impregnated, but on the three fo mpregnated by horses. Of the various theories whic advanced in explanation of this singular fact, of wh lel instances are on record, none bear so much we cently promulgated by Dr. Alexander Harvey, acc the constitution of an impregnated female becom nd tainted with the peculiarities of the impregnat gh the medium of the fœtus, that she necessarily ir iarities to any offspring she may subsequently bea .[1]

DEVELOPMENT.

Changes in the Ovum previous to the Formation of the Embryo.

Of the changes which the ovum undergoes previous to the formation of the embryo, some occur while it is still in the ovary, and are apparently independent of impregnation; others take place after it has reached the Fallopian tube. The knowledge we possess of these changes is derived almost exclusively from observations on the ova of mammiferous animals, especially the bitch and rabbit: but it may be inferred that analogous changes ensue in the human ovum.

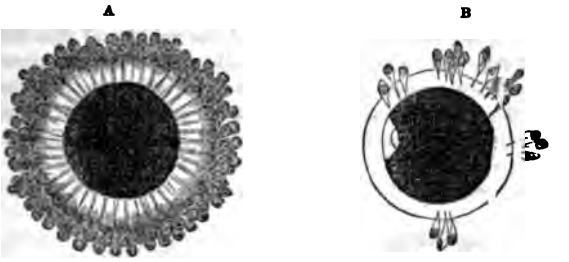
Bischoff (clxxxvii.) describes the yelk of an ovarian ovum after coitus as being unchanged in its characters, with the single exception of being fuller and more dense: it is still granular, as before, and does not possess any of the cells subsequently found in it. The germinal vesicle always disappears, sometimes before the ovum leaves the ovary, at other times not until it has entered the Fallopian tube; but always before the commencement of the metamorphosis of the yelk. Of the manner in which the germinal vesicle, and with it the germinal spot, disappears, and of the changes which they are supposed previously to undergo, much has been written, though little is with certainty known.

The cells of the membrana granulosa, which immediately surround and adhere to the ovum, undergo a peculiar change of form about the time at which the ovum is destined to leave the

[1] For an account of Dr. Harvey's important investigations on this subject, the reader is referred to his original papers in the Monthly Journal of Medical Sciences for 1849 and 1850, or to his Essay on Cross-breeding (cxcix.).

ovary. They become club-shaped, their pointed extremities being attached to the zona pellucida, so as to give the ovum a stellate appearance (see Fig. 121). When the ovum enters the Fallopian tube, these cells lose their spindle or club-like shape, and become

Fig. 121.



A. An ovarian ovum from a bitch in heat, exhibiting the elongated form and stellate arrangement of the cells of the discus proligerus or membrana granulosa around the zona pellucida. B. The same ovum after the removal of most of the club-shaped cells.

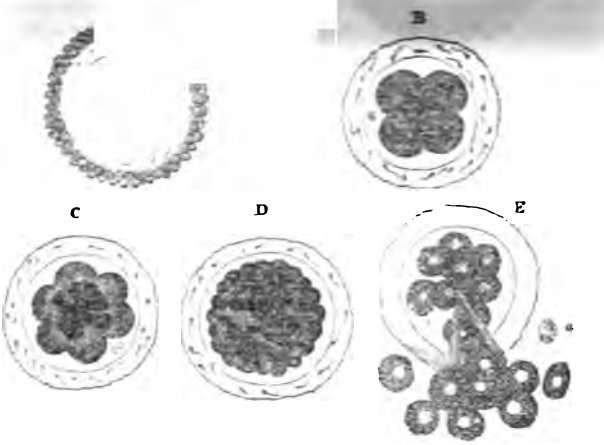
quite round. In the bitch, they continue to invest the ovum in this round shape throughout the whole tract of the Fallopian tube, disappearing only when the ovum reaches the uterus; but, in the rabbit, they wholly disappear at its very commencement.

Besides the disappearance of the germinal vesicle, and in the rabbit, the disappearance also of the cells of the membrana granulosa, the yelk, in the upper part of the Fallopian tube, no longer completely fills the zona pellucida, but contracts, and leaves a clear space between them.

As the ovum approaches the middle of the Fallopian tube, it begins to receive a new investment, consisting of a layer of transparent albuminous or glutinous substance, which forms upon the exterior of the zona pellucida. It is at first exceedingly fine, and owing to this, and to its transparency, is not easily recognized; but at the lower part of the Fallopian tube it acquires considerable thickness, and shortly begins to assume the characters of the *chorion*, into which it, together with the zona pellucida, is subsequently converted. At this part of its transit along the Fallopian tube, the ovum remains still unchanged in structure, and no alteration, beyond increased thickness, is perceived in the zona pellucida. A remarkable phenomenon has, however, been noticed by Bischoff in the rabbit, about this time, namely, the performance by the entire yelk of regular and energetic rotatory movements within the zona pellucida; a phenomenon produced, he says, by the action of vibratile cilia situated upon the surface of the yelk.

The changes which the mammalian ovum undergoes in its passage through the second half of the Fallopian tube, consist in the further formation of the chorion, and in the peculiar process of *cleaving*, or division and subdivision, of the substance of the yelk, which will now be described.[1] The development of the chorion will be considered at a future page.

Bischoff, whose observations were made on rabbits and bitches, states that, when the ovu[illegible] the middle of the Fallopian tube in its transit to [illegible]k, which was previously one compact unif[illegible] resolved into a number of smaller sph[illegible]o, then into four, then eight, then sixteen[illegible]. Each segment contains a



A. Ovum of a bitch, from the Fallopian tube, half an inch from its opening into the uterus, showing the zona pellucida with adherent spermatozoids, the yelk divided into its first two segments, and two small granules or vesicles contained with the yelk in the cavity of the zona. B. Ovum of a bitch from the lower extremity of the Fallopian tube: the cells of the tunica granulosa have disappeared: the yelk is divided into four segments. C. Ovum of bitch from the lower extremity of the Fallopian tube, in a later stage of the division of the yelk. D. An ovum from the uterus: it is larger, the zona thicker, and the segments of the yelk are very numerous. E. Ovum from the lower extremity of the Fallopian tube burst by compression: the segments of the yelk have partly escaped, and in each of them a bright spot or vesicle is visible.

transparent vesicle, like an oil-globule, which is seen with difficulty, especially in the bitch's ovum, on account of its being enveloped

[1] For an account of the process of cleaving in Amphibia and Fish, see Müller's Elements, and the Supplement.

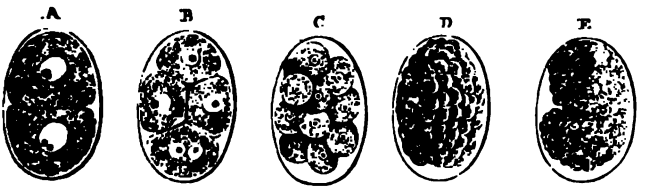
by the yelk-granules, which adhere closely to its surface. He has not been able to detect a nucleus in it, and therefore does not regard it as a true cell. Neither does he regard the globular segments themselves as cells, for neither in the rabbit nor in the bitch can any investing membrane be discerned: they seem to be mere aggregations of yelk-substance around the central body or vesicle.

The cause of this singular subdivision of the yelk is quite obscure: though the immediate agent in its production seems to be the central vesicle contained in each division of the yelk. Originally there was probably but one vesicle, situated in the centre of the entire granular mass of the yelk, and probably derived from the germinal vesicle. This, by some process of multiplication, divides and subdivides: then each division and subdivision attracts around itself, as a centre, a certain portion of the substance of the yelk.

The process is closely identical with changes which ensue in the ova of certain species of Ascaris, except that, in the latter case, they result from the division and subdivision of nucleated cells, which, like the oil-like vesicles in the Mammalian ovum, attract around them certain portions of the substance of the yelk (see Fig. 123).

About the time at which the mammiferous ovum reaches the uterus, the process of division and subdivision of the yelk appears to have ceased, its substance having been resolved into its ultimate

Fig. 123.



Cleaving of the yelk after fecundation. Ascaris nigrovenosa. A. An ovum, the yelk of which is divided into two equal portions; the upper portion contains a cell with a large nucleus, the lower, a similar cell with two small nuclei. B. An ovum, of which the yelk is divided into four masses, three of which possess a single nucleated cell, the fourth two such cells. C. An ovum, the globular masses of whose yelk amount to sixteen, in each of which a nucleated cell is clearly discernible.—After Kölliker (lxxx. 1843). D. and E. are representations of ova from Ascaris acuminata, showing subsequent steps in the process of division which goes on until the globular masses become exceedingly small, and are moulded into the form of the young worm. In the late cells, however, the central cells can be no longer recognized.—After Bagge (clxxx.).

and smallest divisions, while its surface presents a uniform finely granular aspect, instead of its late mulberry-like appearance. The ovum, indeed, appears at first sight to have lost all trace of the

taking place one or two days before the commencement of the period of menstruation.

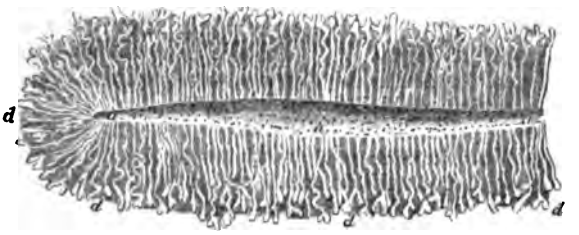
Changes of the Ovum within the Uterus.

It has been remarked that in its passage along the Fallopian tube the ovum is invested externally with a layer of albuminous substance. In birds, the quantity of this albuminous coating is very large, and constitutes what is termed the *white* of the egg; it serves for the nourishment of the embryo until the chick is fully developed, and ready to maintain its existence out of the shell. Mammiferous ova do not require any such large store of nutriment, for when they reach the uterus they enter into such intimate connection with it, by means of structures presently to be described, that their means of subsistence and growth are derived entirely from the parent.

The exterior of the Mammiferous ovum, therefore, acquires only a thin layer of albuminous substance. This shortly becomes intimately united with the zona pellucida, together with which it forms a membrane termed the *chorion*. Shortly after its formation, the chorion sends off from its external surface numerous villous processes, which give it a shaggy or spongy appearance, and which appear to be destined for the absorption of nutriment from the internal surface of the uterus during the earliest period of embryonic life.

Before the impregnated ovum reaches the uterus, certain preparations are made in that cavity for its reception. These changes consist especially in an increased development of the several parts

Fig. 124.



Section of the lining membrane of a human uterus at the period of commencing pregnancy, showing the arrangement and other peculiarities of the glands *d, d, d*, with their orifices, *o, o, o*, on the internal surface of the organ. Twice the natural size.—After E. H. Weber.

composing the mucous membrane of the uterus, which results in the formation of the *membrana decidua*—so called on account of being discharged from the uterus at parturition. The mucous

membrane of the human uterus is abundantly beset with tubular follicles, arranged perpendicularly to the surface. These follicles have not been described as existing in the unimpregnated uterus; but, their appearance immediately after impregnation, and the existence of follicles in the unimpregnated uterus of the bitch, and other animals, leave little doubt of their entering into the structure of the mucous membrane of the human uterus previous to impregnation. Examined s[illegible] pregnation, these glands are found elongated, enlar[illegible] waved and contorted towards their deep and closed e[illegible] h is implanted at some depth [illegible] he tissue of the uterus, and [illegible] nonly dilates into two or three [illegible] d sacculi (Fig. 124). On the [illegible] nal surface of the mucous [illegible] brane may be seen the circu[illegible] rifices of the glands, many [illegible] hich are, in the early period of pregnancy, surrounded by a whitish ring, formed of the epithelium which lines the follicles (Fig. 125).

Fig. 125.

Two thin segments of human decidua after recent impregnation, viewed on a dark ground: they show the openings on the surface of the membrane. 1 is magnified six diameters and 2 twelve diameters. At 1 the lining epithelium is seen within the orifices, at 2 it has escaped. From Dr. Sharpey (xxxii.).

Coincidently with the increasing size of the follicles, the quantity of their secretion is augmented, the vessels of the mucous membrane become larger and more numerous, while a substance composed chiefly of nucleated cells fills up the interfollicular spaces in which the bloodvessels are contained. The effect of these changes is an increased thickness, softness, and vascularity of the mucous membrane, which itself forms the membrana decidua.

The object of this increased development seems to be the production of nutritive materials for the ovum; for the cavity of the uterus shortly becomes filled with secreted fluid, consisting almost entirely of nucleated cells, in which the villi of the chorion are imbedded. The villi of the chorion do not seem to have been ever traced into the follicles, although Bischoff (lxxx. 1847), thinks it probable that they do enter them. But in the bitch they may be easily traced into the dilated glands of the mucous membrane. According to Dr. Sharpey, the glands of the mucous membrane of the bitch's uterus are of two kinds, simple and compound. The former, which are the more numerous, are merely very short unbranched tubes closed at one end (Fig. 126, ^{1},^{1}); the latter (^{2},^{2})

have a long duct dividing into convoluted branches; both open on the inner surface of the membrane by small round orifices, lined with epithelium, and set closely together. After impregnation, the glands of those parts of the mucous membrane which come into immediate relation with the ova greatly enlarge; while the extremity of each compound gland, just before it opens on the surface of the uterus, dilates into a pouch, or cell, filled with whitish secretion, within which is received a process of the chorion. The simple glands also dilate, and receive each a fœtal villus.

When the ovum enters the uterus, it becomes imbedded in the structure of the decidua, which is yet quite soft. The earliest ova which have been observed in connection with the decidua, were not contained free in its cavity, but appeared to be implanted in it or pressed into it from without; the decidua, at the point of entrance of the ovum, being protruded inwards, and the ovum contained in

Fig. 126. Fig. 127.

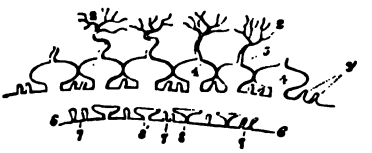


Fig. 126. A vertical section of the mucous membrane, showing uterine glands of the bitch, magnified twelve diameters: 1, 1, simple glands; 2, 2, compound ditto.—From Dr. Sharpey.

Fig. 127. Diagram of part of the decidua and ovum separated, to show their mutual relation: 2, 3, 4, 5, as in the former figure; 6, chorion; 7, villi; 8, 8, fœtal processes of the chorion.—From Dr. Sharpey (xxxii.).

a hollow of its external surface. During the further growth of the ovum, the decidua becomes more and more inverted at this point, the inverted part being received into the cavity of the rest of the membrane. This inverted portion is called the *decidua reflexa*,[1] while the other part of the membrane is called the *decidua vera*. At the part where the uterine expansion of the decidua is interrupted by the reflexion inwards of the decidua reflexa, and where the ovum entered, the place of the decidua vera is supplied by

[1] The mode in which the decidua reflexa is formed is involved in considerable obscurity. For the most recent observations on the subject, consult Sharpey (xxxii. p. 1580); E. H. Weber (clxxxiii.); Coste (xviii. May, 1847); and Goodsir (ii.).

another layer similar to it, and connected at its margins with it, the "decidua reflexa." When young ova are examined in the uterus, both the decidua vera and the decidua reflexa are generally found; but in adult ova this is seldom the case, a part of the decidua being most frequently retained in the uterus. As the ova increase in size, the decidua vera and the decidua reflexa gradually come into contact, and in the third month of pregnancy the cavity between them has quite disappeared. Henceforth it is very difficult, or even quite impossible to distinguish the two layers.

Development of the Embryo.

We have already traced the changes which ensue in the mammalian ovum subsequent to [illegible]tion, as far as the formation of the germinal membrane, w[illegible]iste of a layer of epithelium-like cells inclosing the subs[illegible]he yelk, and immediately in contact with the interna[illegible]e zona pellucida. Most of the subsequent changes [illegible] the formation of the mammalian embryo are sim[illegible]ch take place in the development of the chick, a[illegible]ects similar to those which occur in Amphibia an[illegible] names applied to the several parts are the same [illegible]ee each step in the process may be illustrate[illegible] observations on the development of these low[illegible]

Very soon after the [illegible]erminal membrane presents in the centre of its surface an [illegible] roundish spot, which is pro[illegible] and nuclei of cells, of less trans[illegible]. This space, **the "area germinativa,"** or [illegible] the part in which the embryo first appears. About [illegible] the germinal membrane becomes divisible, in the [illegible] two distinct laminæ. This division [illegible] manifest in the situation of the area germinativa, but [illegible] in this point, and implicates nearly the whole of the germinal membrane. The superior or external layer, which lies next to the zona pellucida, is called the *serous layer;* from it are developed the organs of the animal system of the body, *e. g.*, the bones, muscles, and integuments: the inferior or internal division, in contact with the yelk itself, is named the *mucous layer*, and serves for the formation of the internal or visceral system of organs.

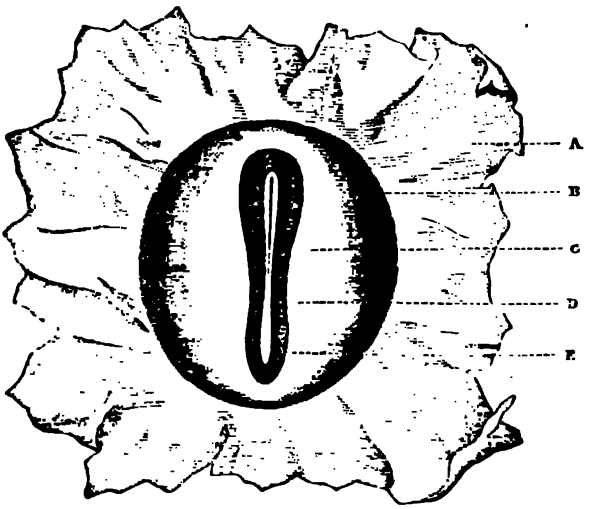
At its first appearance, the area germinativa has a rounded form, but it soon loses this and becomes oval, then pear-shaped, and while this change in form is taking place, there gradually appears in its centre a clear space or *area pellucida* (Fig. 128, c), bounded externally by a more opaque circle, which subsequently becomes the *area vasculosa* (B), so named because of its being the part in which

bloodvessels are first formed. In the formation of these two spaces both the serous and mucous laminæ of the germinal membrane take part. The comparative obscurity of the outer space—the area vasculosa—is due to the greater accumulation of nucleated cells and nuclei at that part than in the area pellucida.

The first trace of the embryo in the centre of the area pellucida consists of a shallow groove or channel, the *primitive groove* (Fig. 128, E), formed in the external or serous fold of the germinal membrane: the mucous fold has no direct share in its production. The groove is wider at its anterior or cephalic extremity, and tapers towards the opposite extremity.

Coincidently with the formation of the primitive groove, two oval masses of cells, the *laminæ dorsales* (D) appear, one on each side

Fig. 128.



Portion of the germinal membrane of a hitch's ovum, with the area pellucida and rudiments of the embryo; magnified ten diameters: A. Germinal membrane. B. Area vasculosa. C. Area pellucida. D. Laminæ dorsales. E. Primitive groove, bounded laterally by the pale pellucid substance of which the central nervous system is composed.—After Bischoff (clxxxiv.).

of the groove. At first scarcely elevated above the plane of the germinal membrane, they soon rise into two prominent masses, the upper borders of which gradually tend towards each other, turning inwards over the primitive groove. Their form changes as that of the area pellucida does; passing gradually with the latter from an

oval to a pyriform shape, and eventually becoming guitar-shaped. According to Bischoff, the part of the inner side of each of these masses which immediately adjoins the primitive groove, shortly becomes pellucid, and is developed into nervous substance. The parts from opposite sides then unite, and convert the primitive groove into a tube, which is the central canal of the cerebro-spinal axis, the surrounding nervous matter constituting the substance of the rudimental spinal cord [illegible] cerebral vesicles, which are thus the first parts of the [illegible]re developed. The shaping out of the three cerel[illegible] divisions of the brain takes place before the primi[illegible]losed over; its cephalic extremity dilating into thr[illegible] Fig. 129). The opposite or

Portion of the germinal membrane, with rudiments of the embryo from the ovum of a bitch. The primitive groove, c, is not yet closed, and at its upper or cephalic end presents three dilatations, B, which correspond to the three divisions or vesicles of the brain. At its lower extremity the groove presents a lancet-shaped dilatation (sinus rhomboidalis) C. The margins of the groove consist of clear pellucid nerve-substance. Along the bottom of the groove is observed a faint streak, which is probably the chorda dorsalis. D. Vertebral plates. —After Bischoff.

caudal extremity of the groove at the same time dilates into a lancet-shaped pouch (the sinus rhomboidalis), which corresponds to the future cauda equina (C). The closure of the canal by means of the internal nervous sides of the laminæ dorsales commences

first at the middle, and then gradually proceeds along its whole length: at the same time the other parts of the corresponding laminæ dorsales of the opposite sides unite and form the rudiments of the head and dorsal part of the body.

Immediately beneath, and in a line parallel with the primitive groove, may be seen, about the same time, a narrow linear mass of cells, the *chorda dorsalis*, which forms the basis around which the vertebral column is developed. The development of this column is early indicated by the appearance of a few square, at first indistinct, plates, the rudiments of vertebræ (Fig. 129, D), which begin to appear at about the middle of each dorsal lamina.

While the dorsal laminæ are closing over the primitive groove, thickened prolongations of the serous layer are given off from the lower margin of each; these are named *laminæ viscerales seu ventrales*. At first, the visceral laminæ proceed on the same plane with the germinal membrane, but by degrees they bend downwards and inwards towards the cavity of the yelk, where they unite and form the anterior walls of the trunk. During these changes an accumulation of cells ensues between the mucous and serous laminæ at the part of the germinal membrane already named the area vasculosa. Within this mass, which constitutes a third or middle layer of the germinal membrane, is laid the foundation for the development of the vascular system. At the circumference of the vascular area, insulated red spots and lines make their appearance, and these soon unite so as to form a network of vessels filled with blood (Fig. 130). The margin of the vascular layer is at first limited and quite circular, being bounded by vessels united in a *circulus venosus*, or *sinus terminalis* (Fig. 132), but it soon extends over the whole surface of the germinal membrane.

Fig. 130.

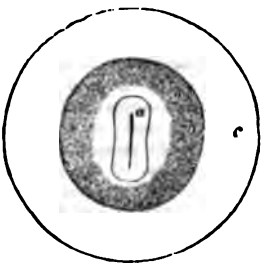


Diagram showing vascular area in the chick. *a*. Area pellucida. *b*. Area vasculosa. *c*. Area vitellina.

About the same time the rudimentary heart is formed in the same layer of the germinal membrane, bending downwards from the cephalic portion of the embryo, so as to inclose the anterior part of the cavity of the body. As shown by Schwann, the bloodvessels are developed originally from nucleated cells. These cells send out processes; the processes from different cells unite; and in this way ramifications and a network are produced. Vessels extend from this network in the area vasculosa into the area pellucida, and join the rudimentary heart. It has, at first, the form of a long slightly-curved tube, prolonged inferiorly into

Fig. 131.

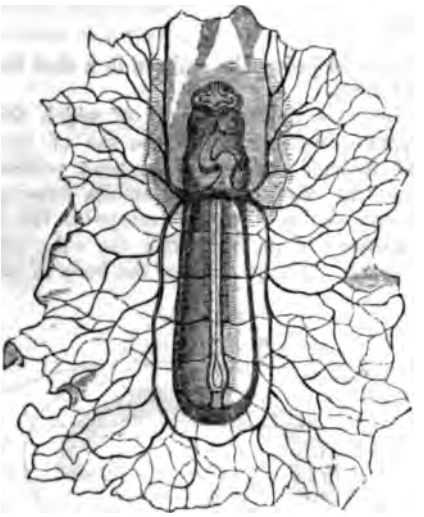
two venous trunks, and superiorly into three or more aortic arches on each side. These arches unite beneath the vertebral column, and form the aorta (see Fig. 131). The vessels extending from the vascular layer now ramify in the animal, as well as in the organic, the embryo, and aid essen- is further development.

primitive state of the em- irculation, the aorta divides ght and a left branch, and continued as the *arteriæ mesentericæ* (*a*, *a*, Fig. 132), germinal membrane, where ly and anastomose until they form a circular venous canal (*s*), which surrounds the area vasculosa. From this venous canal, the *sinus terminalis*, and from the vascular network of the germinal membrane, the blood is brought back by the *venæ omphalo-mesentericæ* (*v*, *v*), which issue from the area vasculosa, at points corresponding to the anterior and posterior extremities of the embryo (see Figs. 132 and 133). Subsequently other veins are developed in the vascular network, which follow the course of the arteries; and at length the terminal sinus entirely disappears, and the whole yelk-sac becomes covered with bloodvessels.

During the above changes, the embryo, together with the immediately contiguous part of the germinal membrane, elevates itself above the level of the rest of that membrane, in the form of a small boat (see Fig. 134), inclosing a cavity open beneath, which is the first condition of the cavity of the trunk of the future animal. The cephalic end of the embryo, with the anterior part of the body, first bends forwards and downwards, and the germinal membrane follows this depression, producing a fold termed the *am-*

lucrum capitis. Shortly afterwards, a similar fold of the germinal membrane is formed at the caudal extremity of the embryo (*vagina caudæ*), and presses from behind forwards beneath it (Fig. 134). These two folds are connected by that part of the boat-shaped embryo, which passes off from the structures of the axis, on each side into the expanded germinal membrane. In this way, the embryo becomes in some measure separated by a constriction, both anteriorly, posteriorly, and at the sides, from the rest of the germinal membrane, above the surface of which it elevates itself, with the cavity of its trunk, still in great part open, turned towards the

Fig. 133.



Embryo from a bitch at the 23d or 24th day, magnified ten diameters. It shows the network of bloodvessels in the vascular lamina of the germinal membrane, and the trunks of the omphalo-mesenteric veins entering the lower part of the S-shaped heart. The first part of the aorta is also seen.—After Bischoff.

yelk. The part of the internal layer of the germinal membrane, which lines the cavity of the embryo, is the primitive form of the intestinal canal. That part of the external layer of the germinal membrane, on the contrary, which descends on each side from the rudimentary axis of the embryo, and contributes to its boat-like form, is continuous with the rudimentary structures which are destined to form the parietes of the trunk, namely, the walls of the neck, chest, and abdomen.

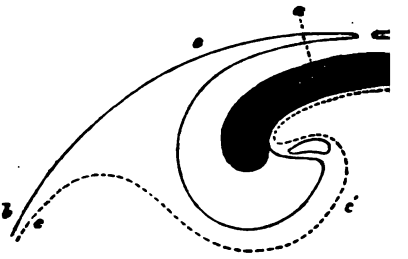
In a further continuation of the above changes, the cephalic,

A longitudinal section of an embryo chick: the embryo; b, the external layer of the germ: involucrum capitis.

meet and coalesce, inclosing the e
(Figs. 135 and 136).

While the inner of the two la
germinal membrane consists form
outer lines the internal surface o
has now become, the chorion. Th
is continuous with the skin of the
union of the parietes of its body v
germinal membrane. The parietes

Fig. 13

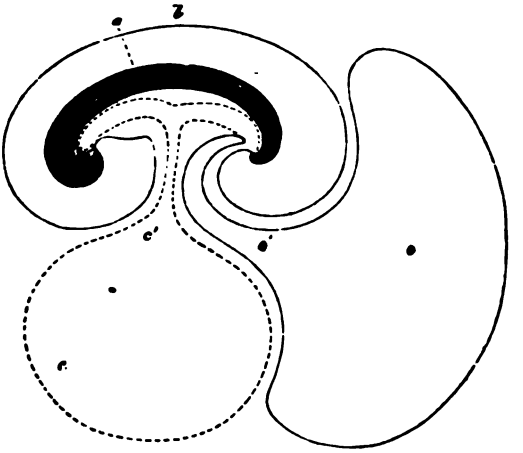


therefore reflected upon them

this period extended over the whole yelk, and become the *vitelline c, yelk-sac*, or, in Mammalia, the *umbilical vesicle*.

By the constriction which the fold of germinal membrane, in hich the abdominal walls are formed, produces at the umbilicus '), the body of the embryo becomes in great measure detached om the yelk-sac or umbilical vesicle, though the cavity of the dimentary intestine still communicates with it through the vitel- ne or omphalo-mesenteric duct, and contains part of the yelk- bstance with which the vesicle was filled. The yelk-sac contains, owever, the greater part of the substance of the yelk, and furnishes source whence nutriment is derived for the embryo. In birds, he contents of the yelk-sac afford nourishment until the end of ncubation: but in Mammalia, the office of the corresponding um- ilical vesicle ceases at a very early period, the quantity of yelk is

Fig. 136.



In figure 136, *a* represents the dorsal structures of the embryo; *b*, the amnion; *c*, the elk-sac or umbilical vesicle; *c'*, the vitelline duct or pedicle of the umbilical vesicle; *o*, the llantois; and *o'*, the urachus.

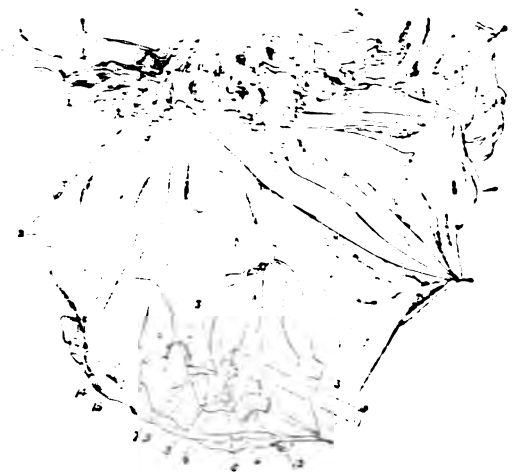
mall, and the embryo soon becomes independent of it by the onnections it forms with the parent. Moreover, in birds, as the ac is emptied it is gradually drawn into the abdomen through the mbilical opening which then closes over it: but, in Mammalia, it lways remains on the outside; and as it is emptied it contracts, hrivels up, and, with the part of its duct external to the abdomen, s detached and disappears either before, or at, the termination of

intra-uterine life, the period of its disappearance varying in different orders of Mammalia.[1]

The walls of the yelk-sac are formed by the several layers of the germinal membrane, of which the mucous and vascular layers become much developed and are actively concerned in the absorption of the contents of the sac. The vessels ramifying in the vascular layer are named, as already said, *omphalo-mesenteric*; their trunks, an artery and two vein[illegible] omen at the umbilicus with the vitelline or umph[illegible]uct. The mucous surface lining the interior of [illegible]he chick especially, highly developed, and presen[illegible]ular folds or processes for the absorption of th[illegible]tents of the sac do not pass directly into the in[illegible] at first, through the pervious vitelline duct, un[illegible]tes, but are absorbed by the omphalo-mesenteric ves[illegible]d to the liver. The vascular folds of the mucous m[illegible]ered by the granules of the yelk, which give them [illegible]olor, and hence led to the vessels being formerly called *vasa rubra*.[2]

The blood-vessels of the umbilical vesicle (omphalo-mesenteric vessels) are well shown in the preparation of a human embryo belonging to Dr. Sharpey.

Fig. 137.



[1] Respecting the changes of the absorbed yelk in the liver of the chick, see p. 198, *note*.

[2] For a minute account of the structure and office of the mucous coat of the umbilical vesicle of the chick, by Mr. Grainger, see Müller (xxxii. p. 1557).

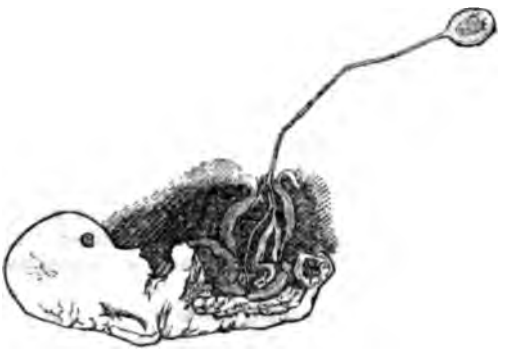
annexed figure is an outline copy of the plate referred to. The ted ovum measured about 1½ inch. Abundant and large villi extended the chorion (1) to the decidua at the part where the cord was attached. amnion (2) is laid open, and the fœtus lies at the bottom of its cavity. vesicula umbilicalis (3), rather more than one- h of an inch in diameter, adheres to the outside ne amnion, connected by its pedicle to the ilical cord. The intestine (4), on leaving the ach, makes a turn to the right; then, after a grade bend, passes through the umbilicus into cord, at first straight (5), then making three in the cord, then returning straight again (6) the abdomen, and terminating at the lower end ie body. The straight returning portion is the e intestine, as indicated by the commencing nm, which appeared at the point where the coils in the cord terminated. (Fig. 138.) The ilical vein (7) may be easily traced to the lower of the liver (9), being there connected with the stinal vessels (vena portæ? 8). (12) The ilical arteries. On tracing back the fine pedicle he umbilical vesicle towards the fœtus, it may een, on approaching the intestine, to consist of filaments, separated by the coil of intestine. of these (11), probably the omphalo-mesenteric , joins the small intestine almost immediately w the stomach, enlarging somewhat at the t of its junction. The other filament (10), the halo-mesenteric artery, proceeds from the nteric vessels. This origin of the omphalo- nteric artery is shown in Fig. 138.

Fig. 138.

Fig. 138 represents the mesentery and intestine of the embryo, shown in Fig. 137, spread out so as to display the mesenteric vessels and the origin of the omphalo-mesenteric artery from one of the main branches.

another, younger fœtus (measuring six-tenths of an inch in length), in possession of Dr. Sharpey, the filament which appears to be identical

Fig. 139.



the omphalo-mesenteric vein was traced further into the abdomen— ely, beneath the intestine to the membrane, and probably to the vessels, ch lie in the concavity of the first intestinal turn. This fœtus is repre-

sented in Fig. 139. The canal of the intestine has been cut tr
and the minute filament or vessel is seen passing beneath it.
Figs. 140, 141, and 142 are drawings of an ovum and emb

Fig. 140. Fig. 141. Fig

Figs. 140, 141, 142 are drawings of an ovum and embryo, representing diffe
the umbilical vesicle.—After Müller.

thirty-fourth day. The ovum was seven lines in diameter; the e
and a half lines in length. The intestine consisted of a canal op
very wide orifice into the umbilical vesicle at the point where the
lamina is reflected into the amnion; so that, in the situation of
duct of the vesicle, there was merely a slight constriction. T
had three pairs of branchial clefts and arches, behind which, in
line, and projecting from the anterior face of the embryo, was si
tubular heart (see Fig. 141).—After Müller.

During the formation of the umbilical vesicle a pear-sh
mass of cells projects from the inferior or caudal extrem
embryo, and is shortly developed into a vesicle named
It has been said by some to proceed directly from the
canal (as represented in Fig. 136); by others from the
bodies or rudimental kidneys; but, at least in the Ma
does not do so; for, as shown by Bischoff, at the time c
appearance, no trace either of the intestinal canal or of the
bodies can be perceived. It subsequently, however, com
with both these parts. As the allantois is developed,
become very vascular, containing the ramifications of wh
the umbilical arteries and vein. It grows rapidly, and
itself until it reaches the chorion, in the villi of which r
the umbilical vessels are brought into connection with t
by means of the *placenta*, presently to be described. In
lia, the vessels conveyed by the allantois are distribute
that part in which the placenta exists; but in birds, the
with its vessels envelops the entire embryo; it forms a v
lar layer, lining the interior of the egg-shell, and afford
means an extensive surface in which the blood may be
In placental Mammalia, the aerating function is discharg
placenta.

As the visceral laminæ close in the abdominal cavity, the allantois is thereby divided at the umbilicus into two portions: the larger proceeding with the umbilical vessels to the chorion, while

Fig. 143. Fig. 144.

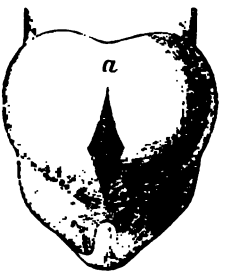


Fig. 143. The lower part of the body of a bitch's embryo, magnified ten diameters. The mucous and vascular layers of the germinal membrane are turned back to show (a) the pedicle of the umbilical vesicle at its entrance into the abdominal cavity. *b, b*, the two cellular masses out of which (in the bitch) the allantois is formed.—After Bischoff.

Fig. 144. The lower extremity of an older embryo. The allantois (*a*) is developed into a single vesicle, but its origin from two symmetrical halves is still shown, especially by the fissure in the middle.—After Bischoff.

the smaller is retained in the abdomen, and converted into the urinary bladder. These two portions are connected together by a constricted part, named the *urachus*.

The Chorion and Placenta.

The mode in which the human embryo is connected with the uterus, for the purpose of drawing from the parent the supplies of nutriment necessary for its growth and development, must now be considered.

It has been already said, that during its passage along the Fallopian tube, the ovum acquires a layer of albumen, and that this subsequently coalesces with the zona pellucida to form the *chorion*, on the surface of which, little villous processes shortly arise, giving the globular mass containing the ovum a shreddy flocculent appearance. The villi of the chorion consist, at first, entirely of cells bounded by an external layer of textureless membrane which gives their form (Goodsir). When the ovum, with its villous chorion, reaches the uterus, the villi become imbedded in the secretion poured forth by the enlarged follicular glands of the mucous membrane of that organ; and from this they doubtless derive the nutriment on which the embryo at first subsists.

Further provision is, however, shortly made for procuring nourish-

Fig. 145.

Diagram of primary ovum, at the time of formation of placenta: a, muco-gelatinous substance, forming the ovum; b, b, Fallopian tubes; c, c, decidua vera, prolonged at c 2 into Fallopian tube; d, cavity of uterus, almost completely occupied by ovum; e, e, angles at which decidua vera is reflected; f, decidua serotina; g, allantois; h, umbilical vesicle; i, amnion; k, chorion, lined with outer fold of serous tunic. An examination of the above diagram, with the remembrance of what has been said before, will explain the parts of which the umbilical cord consists—viz. 1, the remains of the omphalo-mesenteric duct, or pedicle of the umbilical vesicle—accompanied by 2, the omphalo-mesenteric vessels, branches of the mesenteric vessels of the fœtus; 3, the urachus; and, 4, the umbilical vessels, which, in the later period of uterine gestation, constitute the principal part of the umbilical cord. The whole of these parts are held together in the umbilical cord by the sac of the amnion, which, as it is reflected upon the body of the embryo at the umbilicus, forms a sheath to the cord. In mammiferous animals there are generally two umbilical veins as well as two arteries; but in the human subject there is but one umbilical vein with two umbilical arteries. The umbilical arteries are the main branches of the internal iliac arteries. They convey the blood of the fœtus into the placenta, whence it is returned by small veins, which, by their union, form the umbilical vein. The umbilical vein, of which the persistent vena abdominalis of reptiles and Amphibia is the analogue, pours its blood partly into the vena portæ, and partly through the ductus venosus into the vena cava.

ment, by the development of bloodvessels within the villi, and the unction of these with the branches of the umbilical vessels, brought by the allantois to the chorion. The fœtal vessels thus come into intimate relation with the vessels of the uterus. The part at which this relation between the vessels of the fœtus, and those of the parent ensues, is not, however, over the whole surface of the chorion; for, although all the villi become vascular, yet in the human subject, it is at one part only that they are greatly developed, and by their branching give rise, with the vessels of the uterus, to the formation of the *placenta* (Fig. 145).

The ovum appears to have a firm connection with the uterus in all Mammalia, with the exception of the Marsupialia and Monotremata. The means of attachment are always either vascular villi, or folds of the chorion. The chorion receives its bloodvessels from the umbilical vessels of the fœtus, which are distributed upon the al-

Fig. 146.

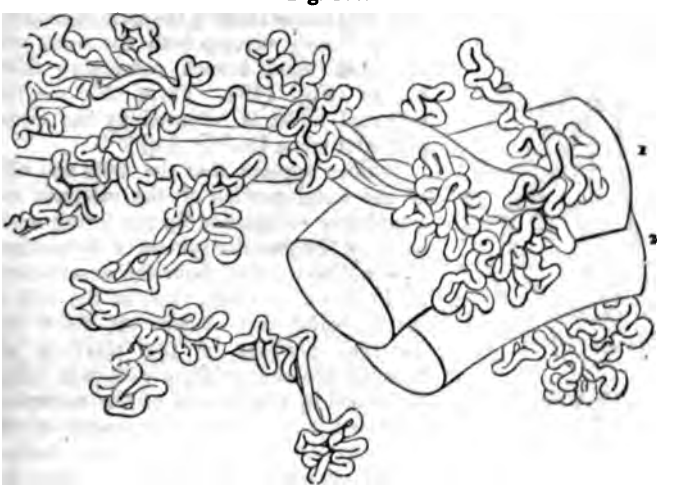
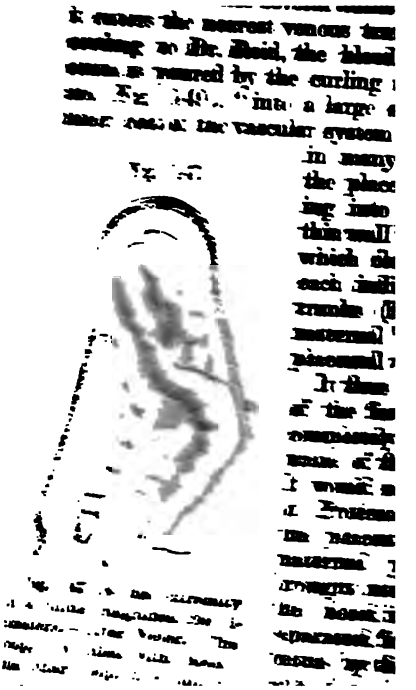


Fig. 146 represents the villi of the fœtal portion of a mature human placenta magnified 90 diameters.—After E. H. Weber. The capillary vessels are filled with injection, and their diameter varies from 1-115th to 1-170th of a French line. 1, the vein; 2, the artery.

antois, and by it are conducted to the chorion. The villi are sometimes distributed over the whole surface of the chorion; sometimes they form a zone around the ovum; at other times they are collected into several masses, or cotyledons, scattered over the chorion; and lastly, in man and some other animals, they form a single placenta upon one side of the chorion.



sets of cells with their investing membrane there exists a space, *d*, into which it is probable that the materials secreted by the one set

Fig. 148.

Fig. 149.

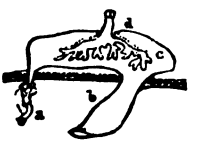


Fig. 148. Transverse section of the uterus and placenta: *a* and *b*, uterine sinuses, with tufts of fœtal placental vessels prolonged into them; *c*, curling artery passing through decidua vera; *d*, decidua vera; *e*, tufts of placental vessels.—J. Reid.

Fig. 149. Connection between the maternal and fœtal vessels: *a*, curling artery; *b*, uterine vein; *c*, placenta; *d*, placental tufts, with inner coat of vascular system of the mother enveloping them.—J. Reid.

of cells of the villus are poured, in order that they may be absorbed by the other set, and thus conveyed into the fœtal vessels.[1]

Fig. 150.

Extremity of a placental villus: *a*, external membrane of the villus continuous with the lining membrane of the vascular system of the mother; *b*, external cells of the villus belonging to the placental decidua; *c c*, germinal centres of external cells; *d*, the space between the maternal and fœtal portions of the villus; *e*, the internal membrane of the villus, continuous with the external membrane of the chorion; *f*, the internal cells of the villus, belonging to the chorion; *g*, the loop of umbilical vessels.—After Goodsir.

DEVELOPMENT OF ORGANS.

It remains now to consider in succession the development of the several organs and systems of organs in the further progress of the embryo.

[1] Although, in the text, mention is made only of the passage of materials from the blood of the mother into that of the fœtus, yet there can be no doubt of the existence of a mutual interchange of materials between the blood of both fœtus and parent, the latter supplying the former with nutriment, and in turn abstracting from it materials which require to be removed. (See on the subject, Dr. A. Harvey, excix.)

Development of the Vertebral Column and Cranium.

The primitive part of the vertebral column in all the Vertebrata is the gelatinous chorda dorsalis, which consists entirely of cells (p. 497). This cord tapers to a point at the cranial and caudal extremities of the animal. In the progress of its development it is found to become inclosed in a membranous sheath, which at length acquires a fibrous [illegible] composed of transverse annular fibres. The chorda dorsalis [illegible] regarded as the azygous axis of the spinal column, [illegible] of the future bodies of the vertebræ, although [illegible] ses into the cartilaginous or the osseous state, [illegible] as in a case within the persistent parts of the [illegible] which are developed around it. It is permanent [illegible] a few animals: in the majority it disappears a[illegible]

The cartilaginous [illegible] are always first developed in pairs of lateral ele[illegible] [illegible]des of the chorda dorsalis. From these lateral elements are formed the bodies and the arches of the vertebræ. In some animals, as the sturgeon, however, the lateral elements of the vertebræ undergo no further development, and it is here that the chorda dorsalis is persistent through life. In the myxinoid fishes the spinal column presents no vertebral segments, and there exists merely the chorda dorsalis with the fibrous layer surrounding its sheath, which is the layer in which the skeleton originates. This fibrous layer also forms superiorly the membranous covering of the vertebral canal.

In reptiles, birds, and mammals, the mode in which the vertebræ are formed around the chorda dorsalis seems to be different. The peculiarity of this type is, at all events, distinct in the class of birds. Here the vertebræ, in that part of the spinal column which belongs to the trunk, are developed from a single pair of elementary parts. When the formation of these parts from the blastema commences, there appears at each side of the chorda dorsalis a series of quadrangular figures, the rudiments of the future vertebræ (Fig. 131, p. 498). These gradually increase in number and size, so as to surround the chorda both above and below, sending out, at the same time, superiorly, processes to form the arches destined to inclose the spinal cord. In this primitive condition, the body and arches of each vertebra are formed by one piece on each side. At a certain period these two primary elements, which have become cartilaginous, unite inferiorly by a suture. The chorda is now inclosed in a case, formed by the bodies of the vertebræ, but it gradually wastes and disappears. Before the disappearance of the chorda, the ossification of the bodies and arches of the vertebræ begins at distinct points.

The ossification of the body is first observed at the point where

the two primitive elements of the vertebræ have united inferiorly. Those vertebræ which do not bear ribs, such as the cervical vertebræ, have generally an additional centre of ossification in the transverse process, which is to be regarded as an abortive rudiment of a rib. In the fœtal bird, these additional ossified portions exist in all the cervical vertebræ, and gradually become so much developed in the lower part of the cervical region as to form the upper false ribs of this class of animals. The same parts exist in Mammalia and man; those of the last cervical vertebræ are the most developed, and, in children, may, for a considerable period, be distinguished as a separate part on each side, like the root or head of a rib.

The true cranium is a prolongation of the vertebral column, and is developed at a much earlier period than the facial bones. Originally, it is formed of but one mass, a cerebral capsule, the chorda dorsalis being continued into its base, and ending there with a tapering point. This relation of the chorda dorsalis to the basis of the cranium is persistent through life in some fish, *e. g.*, the sturgeon. The first appearance of a solid support at the base of the cranium observed by Müller in fish, consists of two elongated bands of cartilage, one on the right, and the other on the left side, which are connected with the cartilaginous capsule of the auditory apparatus, and united with each other in an arched manner anteriorly beneath the anterior end of the cerebral capsule. Hence, in the cranium, as in the spinal column, there are at first developed at the sides of the chorda dorsalis two symmetrical elements, which subsequently coalesce, and may wholly inclose the chorda.

At a later period the base of the cranium contains three parts analogous to the bodies of vertebræ; the most anterior of which, in the majority of animals, is small, and its development frequently abortive, whilst in man and mammiferous animals the three are very distinct. These parts are developed by the formation of three distinct points of ossification, one behind the other, in the basilar cartilage. The three ossified portions become united by sutures, and in mammals form a rod-like body, tapering towards its anterior extremity, and giving attachment at its sides to the lateral parts of the three vertebræ.

Development of the Face and Visceral Arches.

Before the development of the face, the visceral cavity of the cephalic region is formed superiorly by the primitive rudimentary structure which contains the encephalon, the cerebral capsule; whilst the lower and lateral walls of that cavity are formed by the anterior "visceral arch." At this period there is no nasal cavity, and the visceral cavity of the head extends uninterruptedly from the first visceral arch to the cerebral capsule. In birds and mammiferous animals there are three *visceral arches*, and also three *vis-*

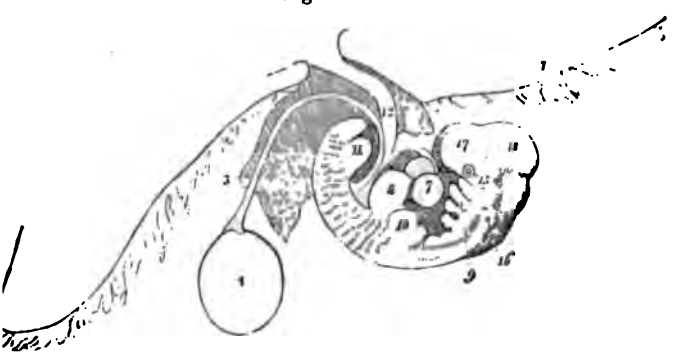
ıe anormal cleft palate and the congenital cleft between the upper axillary and the intermaxillary bone, and of those congenital fis-ures which pass between the intermaxillary bone and upper jaw, ı far upwards as the orbital cavity. Congenital clefts of this kind re the results of an arrest of development occurring during the rimitive conditions of the parts.

The first visceral arch, according to Reichert, produces the su-erior maxillary apparatus, the under jaw, and a part of the ossi-ula auditûs, namely, the malleus and the incus. From the second isceral arch are formed the stapes of the ear, and the suspensory pparatus of the hyoid bone, *i.e.*, the styloid process of the tem-oral bone, the ligamentum stylo-hyoideum, and the smaller cornu f the os hyoides. The posterior cornua, and the body of the ıyoid bone, are developed from a cartilaginous band contained n the third visceral arch.

Development of the Extremities.

The extremities are developed in an uniform manner in all ver-ebrate animals. They appear in the form of leaf-like elevations rom the parietes of the trunk (see Fig. 152), at points where

Fig. 152.

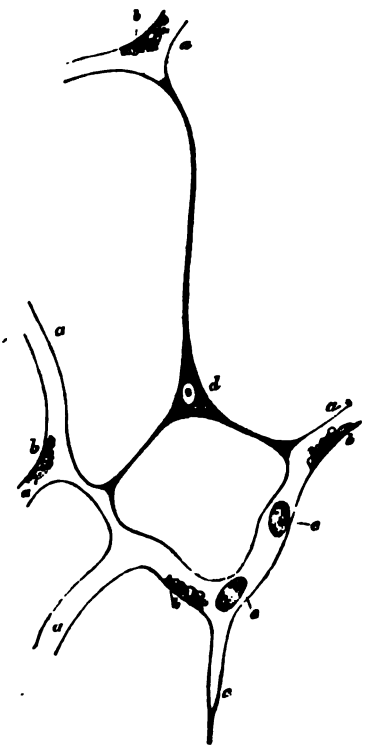


A human embryo of the fourth week, 3½ lines in length: 2, the chorion; 3, part of the amion; 4, umbilical vesicle with its long pedicle passing into the abdomen; 7, the heart; the liver; 9, the visceral arch destined to form the lower jaw, beneath which are two ıer visceral arches separated by the branchial clefts; 10, rudiment of the upper extremi-. 11, that of the lower extremity; 12, the umbilical cord; 15, the eye; 16, the ear; 17, cerebral hemispheres; 18, the optic lobes or corpora quadrigemina.

ore or less of an arch will be produced for them within. The imitive form of the extremity is nearly the same in all Verte-ata, whether it be destined for swimming, crawling, walking, or

its meshes. The prolongations by which the vessels com-
te with the star-shaped cells, consist at first of narrow-pointed
ons from the side of the vessels, which gradually elongate
ey come in contact with the radiated processes of the cells.
ckness of such a prolongation often does not exceed that of
of fibrous tissue, and at first it is perfectly solid; but by
, especially after its junction with a cell, or with another
ation, or with a vessel already permeable to blood, it en-
and a cavity then forms in its interior (see Fig. 153).

Fig. 153.



y bloodvessels of the tail of a young larval frog. Magnified 350 times.—After
a, capillaries permeable to blood; *b*, fat granules attached to the walls of the
d concealing the nuclei; *c*, hollow prolongation of a capillary, ending in a point;
hing cell with nucleus and fat-granules; it communicates by three branches with
ions of capillaries already formed; *e*, blood-corpuscles, still containing granules

With Kölliker's account our own observations, made on the fine gelatinous tissue conveying the umbilical vessels of a sheep's embryo to the uterine cotyledons, completely accord. This tissue is well calculated to illustrate the various steps in the development of bloodvessels from elongating and branching cells (see clxxiv. p. 104).

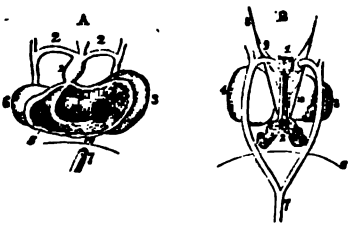
About the time that the heart at its lower extremity receives the venous trunks, and at its [illegible]nity divides into the arterial trunks or aortic arches [illegible]rved from a straight into a horseshoe form, and sho[illegible]o three cavities (Fig. 154). Of these three cavities, [illegible]loped in all Vertebrata, the

Heart of the chick at the 45th, 65th, and 85th hours of incubation: 1, the venous trunks; 2, the auricle; 3, the ventricle; 4, the bulbous arteriosus.—After Dr. Allen Thomson.

most posterior is the simple auricle; the middle one the simple ventricle; and the most anterior the bulbus arteriosus. These three parts of the heart contract in succession. The auricle and the bulbus arteriosus, at this period, lie at the extremities of the horseshoe. The bulging out of the middle portion inferiorly gives the first indication of the future form of the ventricle. (See Fig. 154.) The great curvature of the horseshoe, by the same means, becomes much more developed than the small curvature between the auricle and bulbus; and the two extremities, the auricle and bulb, approach each other superiorly, so as to produce a greater resemblance to the later form of the heart, whilst the ventricle becomes more and more developed inferiorly. The heart of fishes retains these three cavities, no further division by internal septa into right and left chambers taking place. In Amphibia, also, the heart throughout life consists of the three muscular divisions which are so early formed in the embryo; but the auricle is divided internally by a septum into a pulmonary and a systemic auricle. In reptiles, not merely the auricle is thus divided into two cavities, but a similar septum is more or less developed in the ventricle. In birds, mammals, and the human subject, both auricle and ventricle undergo complete division by septa; whilst in these animals, as well as in reptiles, the bulbus aortæ is not permanent, but becomes lost in the ventricles. The septum dividing the ventricle commences

at the apex and extends upwards. (See Fig. 155.) When it is complete, a septum is developed in the bulbus aortæ separating

Fig. 155.



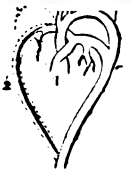
Heart of a human embryo of about the fifth week. A, the heart opened on the abdominal aspect: 1, the bulbus arteriosus; 2, two aortic arches which unite posteriorly to form the aorta; 3, the auricle; 4, the opening from the auricle into the ventricle (6), which is laid open; 5, the septum rising from lowest part of the cavity of the ventricle; 7, the vena cava inferior. B, The same heart viewed from behind: 1, the trachea; 2, the lungs; 3, the ventricle; 4, 5, the large atrium cordis, or auricle; 6, the diaphragm; 7, the aorta descendens; 8, the nervus vagus; 9, its branches; 10, continuation of the nervus vagus.—After Von Baer.

the roots of the proper aorta and the pulmonary artery. The septum of the auricles is developed from a semilunar fold which extends from above downwards. In man, the septum between the ventricles, according to Meckel, begins to be formed about the fourth week, and at the end of eight weeks is complete. The septum of the auricles, in man and all animals which possess it, remains imperfect throughout fœtal life. When the partition of the auricles is first commencing, the two venæ cavæ have different relations to the two cavities. The superior cava enters, as in the adult, into the right auricle; but the inferior cava is so placed that it appears to enter the left auricle, and the posterior part of the septum of the auricle is formed by the Eustachian valve, which extends from the point of entrance of the inferior cava. Subsequently, however, the septum, growing from above downwards, becomes directed more and more to the left of the vena cava inferior. During the entire period of fœtal life, there remains an opening in the septum, which the valve of the foramen ovale, developed in the third month, imperfectly closes.

Aortic Arches and Pulmonary Vessels.—In the early embryos of all vertebrate animals the blood is distributed from the bulbus aortæ in arches towards either side, and, after passing round the circumference of the visceral cavity, is again collected in front of the vertebral column into a single vessel, the aorta descendens. The aortic arches are always several in number, and, at first, lie in connection with the visceral arches. In those animals which

breathe by branchiæ, and in which the visceral arches partly serve for the formation of the branchial apparatus, each of the aortic arches is resolved into two parallel vessels, one arterial, which comes from the heart, and ramifies wholly in the branchiæ, and the other venous, which arises in the branchial laminæ, and unites with the veins of the other branchiæ in front of the aorta to form the descending aorta. In the Amphibia, the same structure exists for a certain period; but, afterwards, the branchial vessels are again transformed into three aortic arches, which, when the branchial apparatus has ceased to exist, sink deeper into the thoracic cavity and become permanent.

In Mammalia, the aortic arches are soon reduced to three, one of which is the persistent arch [illegible]ta, whilst the other two are the ductus arteriosi of the [illegible] artery. Of these ductus arteriosi the right also dis[illegible] that, during the remainder of fœtal life, only two ar[illegible] exist, one arising from the right, and the other from [illegible]le (Fig. 156). The former



Plan of the transformation of the system of aortic arches into the permanent arterial trunks in mammiferous animals; after Von Baer. 1, situation of the original single trunk which arose from the single ventricle, and which has become divided into two tubes: it gave off five pairs of aortic arches, which terminated in the two roots of the aorta (2, 2'). Those of the arches which are obliterated at a very early period, are marked by dotted lines. The first arch of the right side, with the root of the aorta of that side (2) which remains longer, and forms the right ductus arteriosus, is drawn as a very narrow vessel, with a dotted line on each side. The vessels which still exist at birth, are drawn of the full size. These are the first arch of the left side, constituting the ductus arteriosus Botalli, which is in greater part obliterated soon after birth, and the second arch of the left side, constituting the permanent arch of the aorta (3). The subclavian arteries (4) and the carotid arteries (5) are formed from parts of the other primitive aortic arches. After the obliteration of the left ductus arteriosus, the pulmonary arteries are the only remains of the first pair of aortic arches.

of these gives off the arteries to the lungs, the latter, the vessels to the upper parts of the body. These two arches are of equal size, and so remain until the fœtus has attained its maturity. After

birth, the posterior portion of the arch, which arises from the right ventricle (the ductus arteriosus Botalli), rapidly becomes narrowed, and in the course of the first few weeks after birth, its cavity is entirely obliterated: the anterior portion becomes the trunk of the independent arteriæ pulmonales. At the same time, the closure of the foramen ovale takes place.

Veins.—The conformation of the venous system also is at first the same in the embryos of all vertebrate animals, and subsequently departs in various ways from the common primitive type. In the original condition, there are two anterior venous trunks (the jugular veins), and two posterior trunks, the *cardinal veins*. One of the anterior trunks, and one of the posterior, unite on each side, and form a transverse canal—the ductus Cuvieri. The two ductus Cuvieri unite beneath the œsophagus, to form a shorter main canal, which enters the auricle—at that time a simple cavity. The cardinal veins are originally formed by the caudal veins, branches from the kidneys and Wolffian bodies, and others from the dorsal parietes of the trunk, which are, at a later period, the intercostal and lumbar veins; and in animals which have lower extremities, the two cardinal veins also receive the crural veins.

The omphalo-mesenteric vein, vena omphalo-meseraica, which receives the veins of the mesentery, is common to all vertebrate animals. It passes with the two ductus Cuvieri to the auricle. When the liver is formed, this vein gives branches to it, and receives from it others, the venæ hepaticæ. Between the two sets of hepatic veins the trunk of the omphalo-mesenteric becomes obliterated, and then the vena portæ is formed as an independent vessel conveying blood to the liver, while the same blood is carried out of the organ by the distinct venæ hepaticæ.

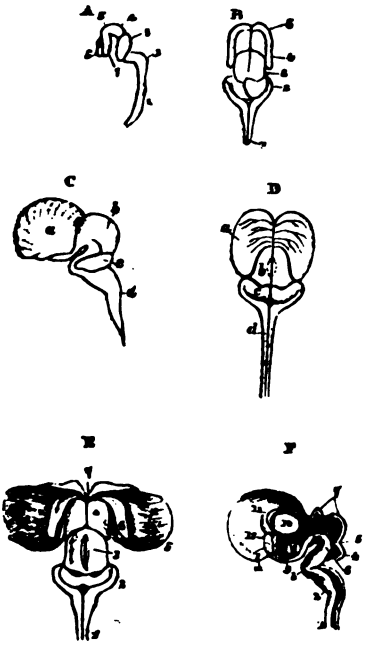
The umbilical vein originally terminates in that part of the omphalo-mesenteric vein which is about to enter the heart, and which subsequently forms the most anterior or superior part of the vena cava inferior. At a later period it sends branches to the liver, while its trunk and the inferior vena cava remain connected by the ductus venosus.

The circulation of the fœtus is essentially distinguished from that of the adult human subject by the mingling of the blood of the two auricles, which takes place through the opening in their septum, also by the further mixture of the blood of the two sides of the heart which is effected through the medium of the ductus arteriosus Botalli, and further by the circumstance of part only of the blood of the right ventricle being sent to the lungs. All the blood of the body, or all the blood which the two ventricles emit, except the small quantity which the lungs receive from the right ventricle, is returned to the right auricle. The blood of the left ventricle is sent to the upper parts and also to the lower parts of the body;

spinal nervous system are formed has
The dorsal laminæ, the inner border
the canal of the spinal cord, seem to l
of the medulla oblongata. Between
extremity of the canal, several vesicul
of the brain, are developed. (See Fig.
by Von Baer in the chick, the cerebell
duce it, the laminæ, after having form
again superiorly and anteriorly, and in
into the vesicle of the optic lobes or
largest of the cerebral vesicles. The v
optic lobes is the vesicle of the third
and at first the most anterior. In fro
vesicles of the cerebrum. (See Fig. 1
of special sense are originally hollow p
the auditory nerve arising from the fo
the third, and the olfactory nerve from t
most essential parts of the organs of spec
their origin, diverticula, or parts protrud
a certain period the vesicle of the corpo
increase in size equally with the other
hemispheres become most rapidly develop
so as to cover the parts situated behind
D.) The cerebral ganglia are produce
walls of the primary vesicles; the corpora
rior or cerebral vesicles, and the optic thal
third ventricle. (Fig. 157, c.)

According to Professor Rotzius (xxxx
or portions of t

Fig. 157.



Early forms of the brain in the embryo, after Tiedemann. A. Brain and spinal cord of an embryo of the seventh week: 1, spinal cord; 2, enlargement of the spinal cord where it makes a bend forwards; 3, cerebellum; 4, optic lobes; 5, optic thalami; 6, membranous hemispheres of the cerebrum; 7, prominence analogous to the corpus striatum. B. Brain of an embryo of the ninth week: 1, spinal cord; 2, cerebellum; 3, optic lobes; 4, optic thalami, inclosing the third ventricle; 5, cerebral hemispheres. E. Brain of an embryo of the twelfth week, viewed from above, the membranous walls of the hemispheres being reflected to either side: 1, spinal cord; 2, cerebellum; 3, optic lobes; 4, optic thalami, between which the third ventricle lies; 5, the walls of the hemispheres; 6, corpora striata; 7, commencement of the corpus callosum. F. Perpendicular section of the same brain; 1, spinal cord; 2, bend of the cord forwards; 3, second bend of the cord upwards; 4, cerebellum; 5, thin laminæ connecting the cerebellum with the optic lobes; 6, crura cerebri; 7, optic lobes or corpora quadrigemina; 8, cavity of the third ventricle; 9, the infundibulum; 10, optic lobe; 11, optic nerves; 12, margin of the fissure leading into the lateral ventricle; 13, corpus callosum, at this period perpendicular in its direction.

Development of the Organs of Sense.

The eye is in part developed as a protruded portion of the vesicle of the third ventricle of the brain, and it contains part of the membranes of the brain, namely, the fibrous and the vascular tunic.

The retina is originally a vesicle-like protrusion of the brain, with the cavity of which it communicates through the medium of the tubular optic nerve (Fig. 158, A). The sac of the transparent

Fig. 158.

Development of the eye: after Huschke. A, longitudinal section of an eye of an embryo chick of five days, enlarged thirty times. The vascularity of the retina and optic nerve are seen, the whole being covered by the external tegument. c, the cephalic part of an embryo chick of the first half of the third day of incubation, magnified seven times; showing the eye with the capsule of the lens still open, surrounded by the retina, which is folded so as to consist of two layers, and presents the cleft interiorly. There are also seen the tubular looped heart, three branchial or visceral arches, and the labyrinth of the ear still open. B, is a section of the eye of the same embryo, through the middle of the lens, enlarged thirty times. The semicircular layers of membrane are seen. The most internal is the very thick capsule of the lens; the next is the true retina, the most external is Jacob's membrane. D, the eye of a chick of the third day of incubation, showing the same parts as figure C on a larger scale. E, is the section of an eye at the fourth day of incubation of the chick, magnified thirty times. The capsule of the lens is now closed, is covered with conjunctiva, and contains a conical nucleus, the lens. The vitreous humor is developed between the capsule of the lens and the retina; external to the two layers of the retina is the sclerotic coat.

media which the eye afterward contains communicates at no period with the cavity of the brain. The capsule of the lens appears to be developed from an inverted portion of the common integuments, and consequently is at a certain period open externally (Fig. 158, B). The inversion of the tegument from without, depresses the external convex surface which the vesicle of the retina has, on the second day of incubation, towards the canal of the optic nerve,

l the anterior half of the vesicle is thus reflected inwards upon lf in the manner of a serous sac. The inverted layer becomes future retina; the external layer, the membrana Jacobi.

The iris is formed rather late, but its circle is complete at its t development. In the eye of the fœtus of Mammalia and man pupil is closed by a delicate membrane, the *membrana pupil-is*, the bloodvessels of which are derived from the anterior sur-e of the iris. From the pupillary margin of the iris there like-se extends backwards the vascular *membrana capsulo-pupillaris*, ich connects the margin of the capsule of the lens with the rgin of the iris.

The eyelids of the human subject and mammiferous animals, e those of birds, are first developed in the form of a ring. They en extend over the globe of the eye until they meet and become nly agglutinated to each other. But before birth, or in the rnivora after birth, they again separate.

The *ear* likewise consists of a part developed from within and one formed externally. The labyrinth is developed upon the llow protruded part of the brain which forms the auditory nerve. appears first in the form of an elongated vesicle at the hinder t of the head of very young embryos above the second so-named nchial cleft. From it is developed a second vesicle, the rudi-nt of the cochlea, the convolutions of which are then formed. semicircular canals are produced, as diverticula of the vesti-e, which terminate by again communicating with the same ity.

The Eustachian tube, the cavity of the tympanum, and the ernal auditory passage, are remains of the first branchial cleft. membrana tympani divides the cavity of this cleft into an in-nal space, the tympanum, and the external meatus. The mucous nbrane of the mouth, which is prolonged in the form of a rticulum through the Eustachian tube into the tympanum, the external cutaneous system, come into relation with each er at this point, the two membranes being separated only by the per membrane of the tympanum.

Development of the Alimentary Canal.

The alimentary canal, which, as already described, is a kind of rticulum from the umbilical vesicle, is at first an uniform ight tube, which gradually becomes divided into its special s, stomach, small intestine, and large intestine (Fig. 159). stomach originally has the same direction as the rest of the al; its cardiac extremity being superior, its pylorus inferior. first changes of position which the alimentary canal undergoes sist in the stomach assuming an oblique direction, and in the ll intestine taking a new course from the stomach towards the

...and after making an abrupt bend there, returning towards the middle of the body in order to make its final curve to reach the anus. The limit between the small and the large intestine lies in the part returning from the umbilicus, the ductus omphalo-mesenteric being connected with the lower part of the small intestine (see

Fig. 130.

...see Fig. 133.

gland first appears as a simple canal with budlike processes (Fig. 160), lying in a gelatinous nidus, or blastema, and communicating with the cavity of the mouth. As the development of the gland advances, the canal becomes more and more ramified, increasing at the expense of the blastema in which it is still inclosed. The branches or salivary ducts constitute an independent system of closed tubes (Fig. 161). The pancreas is developed exactly as the salivary glands.

Fig. 160. Fig. 161.

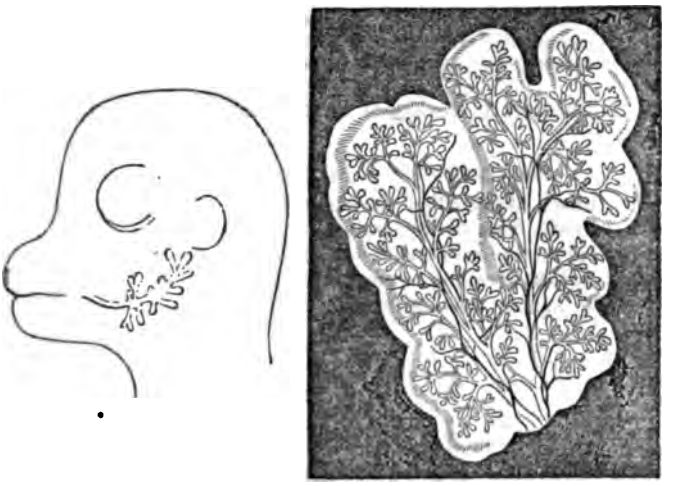


Fig. 160. First appearance of parotid gland in the embryo of a sheep.

Fig. 161. Lobules of the parotid, with the salivary ducts, in the embryo of the sheep at a more advanced stage.

The liver in the embryo of the bird is developed by the protrusion, as it were, of a part of the walls of the intestinal canal, in the form of two conical hollow branches which embrace the common venous stem (Fig. 162). The cones increase in length, pushing before them ramifications of bloodvessels, while their base becomes gradually narrowed, and assumes the form of a cylindrical duct. At the same time internal ramifications are developed in the cavities of the cones, and these become united at their base, in consequence of more and more of the surrounding part of the intestinal parietes being taken up to form them, till at last the part that separated them is removed to a distance from the intestine; and the cavities, originally double, open by one mouth into the intestine.

Fig. 102.

the fifth day of incubation. a heart; ... of which the liver (d) is enveloped; ...

...rticulum from the hepatic ...

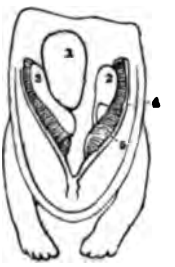
...

...

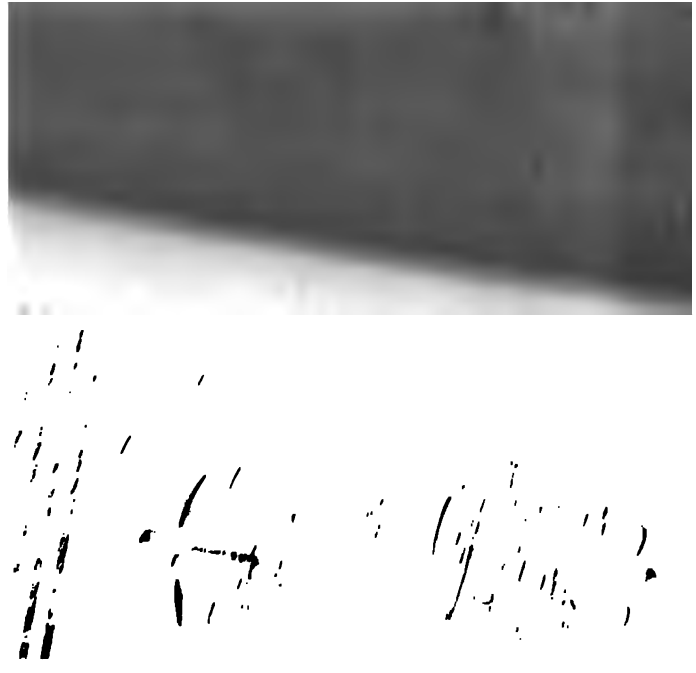
They are organs peculiar to the embryonic state, and may be regarded as temporary, though not rudimental, kidneys; for they seem to discharge the functions of these latter organs, though they are not developed into them. They probably bear the same relation to the persistent kidneys, as the branchiæ of Amphibia do to the lungs which succeed them.

In Mammalia, the Wolffian bodies are bean-shaped, and are composed of transverse cæcal canals, united by an excretory duct which leads from the lower extremity of the organ to the sinus urogenitalis or cloaca of the fœtus.. (See Fig. 164, 4.) The kidneys (2) and suprarenal capsules (1) are developed behind them. Their size is at first so great that they entirely conceal the kidneys; but in proportion as the latter bodies increase in size they grow relatively smaller, and come to be placed more inferiorly. Along the outer border of the gland runs the efferent part of the generative apparatus (5), viz., the Fallopian tube or the vas deferens, which at first has the same conformation, and terminates by a free extremity; whilst the testicle or ovary (2) is formed independently at the internal excavated border of the organ. Subsequently, the efferent tube and the testicle in the male become connected by transverse vessels, whilst in the female the extremity of the efferent tube merely acquires an open mouth. In both sexes the Wolffian bodies entirely disappear, and are not converted into any other organ. The epididymis is developed independently, that part which consists of the coni vasculosi being formed of the communicating tubes which connect the efferent tube with the testis, and the rest being constituted by the convolutions of the efferent tube itself. All that part of the efferent tube of the generative apparatus which is thrown into strongly marked convolutions along the outer border of the Wolffian body, contributes to the formation of the epididymis, and from the point where the convolutions cease, a band or ligament, the gubernaculum testis Hunteri, which was developed before these convolutions of the tube were visible, and contains fibres of the cremaster muscle, passes off to the inguinal canal, and subsequently serves to guide the testis into the scrotum. In the female the tube remains free from convolutions, but from the same point as in the male, a ligament, afterwards the round

Fig. 164.

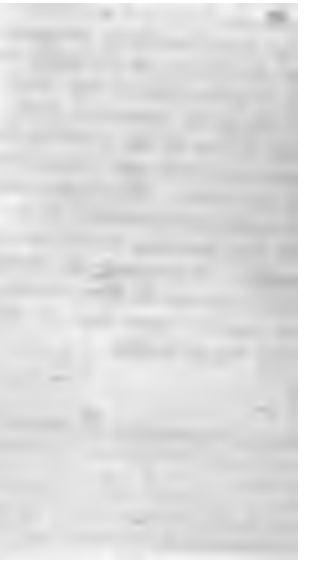


Magnified representation of the urinary and generative organs of human embryo measuring eight lines in length. 1, the suprarenal capsule of the right side, totally concealing the corresponding kidney which lies behind it; 2, kidney and ureter of the left side exposed by the removal of the suprarenal capsule; 3, testis or ovary of the right side; 4, Wolffian body; 5, Fallopian tube, or vas deferens.—After Müller.



the urachus. Subsequently, it becomes divided by a process of division, extending from before backwards or from above downwards, into a "pars urinaria" and a "pars genitalis." The former, extending towards the urachus, is converted into the urinary bladder, whilst from the latter are formed the vesiculæ seminales in the male and the middle portion of the uterus in the female (see Fig. 165, B).

The external parts of generation are at first the same in both sexes. The opening of the genito-urinary apparatus is, in both sexes, bounded by two folds of skin, whilst in front of it there is formed a penis-like body surmounted by a glans, and cleft or furrowed along its under surface. The borders of the furrow diverge posteriorly, running at the sides of the genito-urinary orifice internally to the cutaneous folds just mentioned (see Fig. 165, B, D). In the female, this body becoming retracted forms the clitoris, and the margins of the furrow on its under surface are converted into the nymphæ, or labia minora, the labia majora pudendæ being constituted by the great cutaneous folds. In the male fœtus, the margins of the furrow at the under surface of the penis unite at about the fourteenth week, and form that part of the urethra which is included in the penis. The large cutaneous folds form the scrotum, and at a later period, namely, in the eighth month of development, receive the testicles, which descend into them from the abdominal cavity. Sometimes the urethra is not closed, and the deformity called hypospadia then results. The appearance of hermaphroditism may in these cases be increased by the testis being retained within the abdomen.



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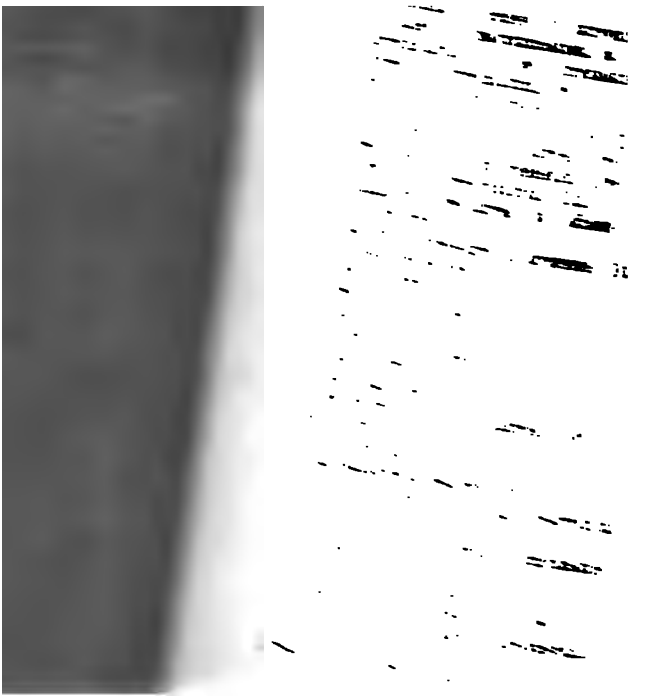

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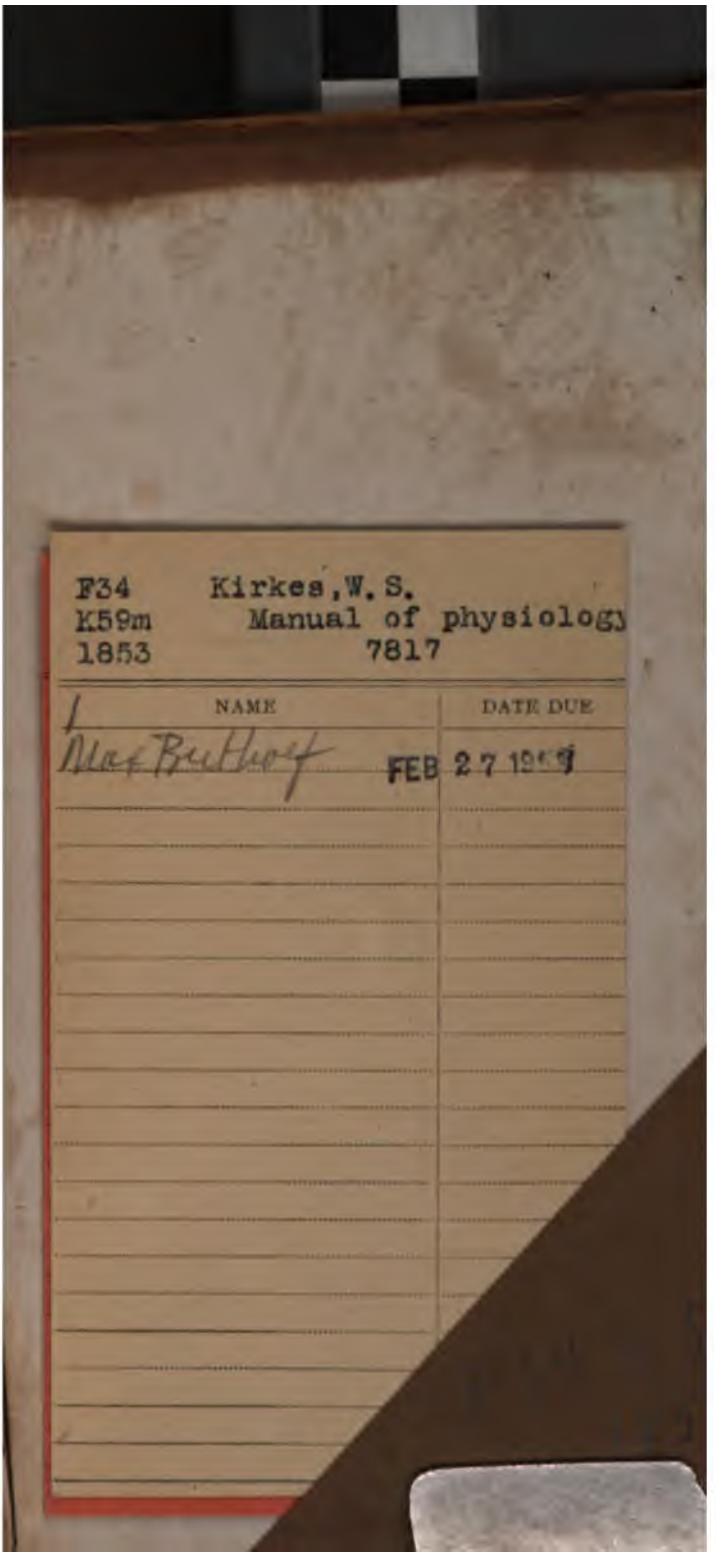
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